1.0

2.8　2.5

3.2

2.2

2.0

1.1

1.8

1.25　1.4　1.6

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TL 579

CRREL

ADA037480

WINDOWS AS AN ENERGY FACTOR

F. Hagman

D D C

MAR 29 1977

RECEIVED

D
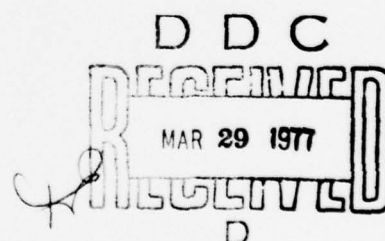
REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Draft Translation 579	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) WINDOWS AS AN ENERGY FACTOR		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) F. Hagman		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE January 1977
		13. NUMBER OF PAGES 56
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

ENERGY   WINDOWS
INSULATION

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Within the framework of research on "windows as an energy factor", this report analyzes the psosibilities for saving energy through added insulation of windows. This is assumed to be accomplished with insulated outside shutters. The analysis of the thermal function of windows, with and without insulated shutters, is based on computer evaluations performed by Dr. E. Isfalt.
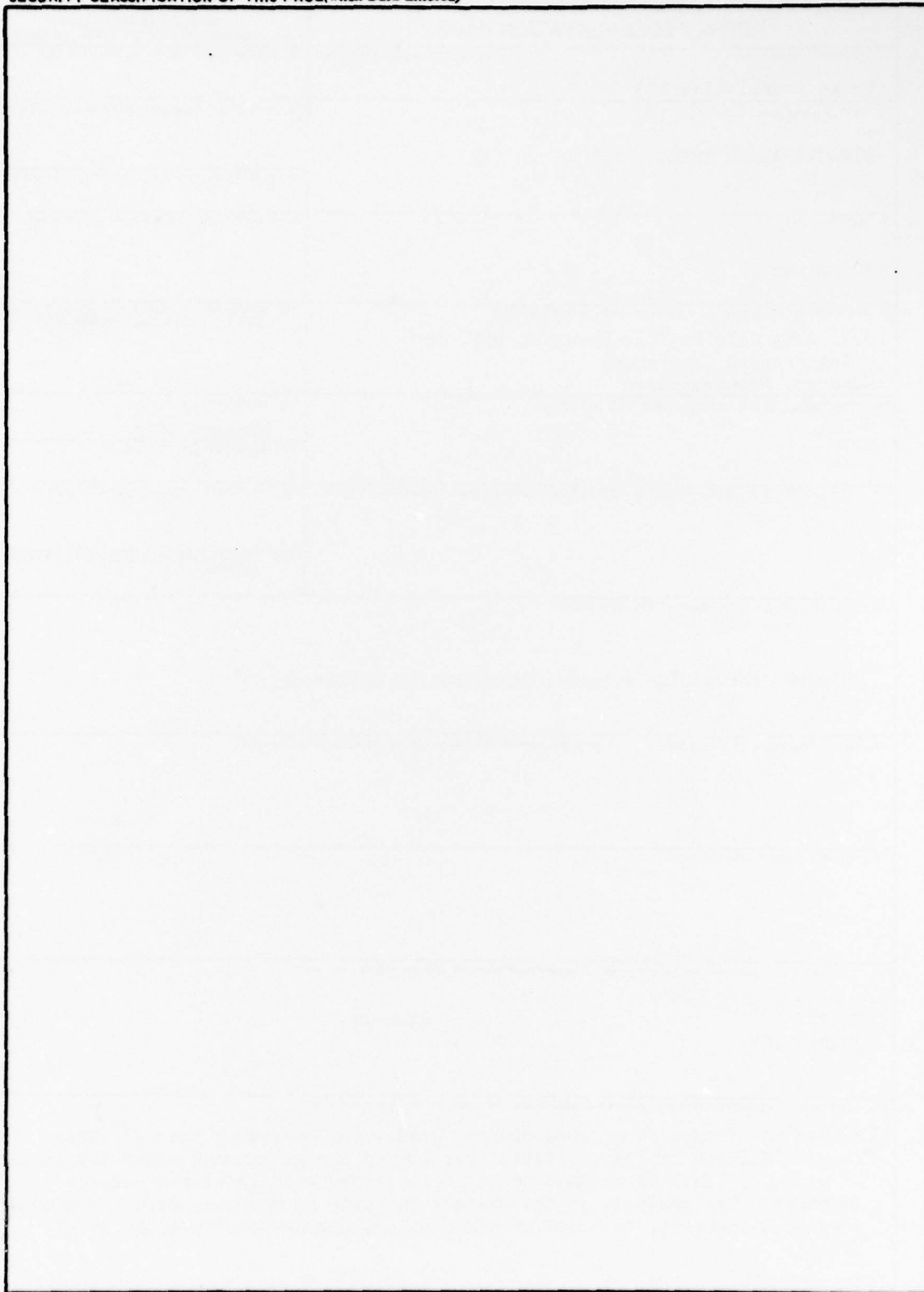
Write Section

Butt Section ☐

☐

CODES

SPECIAL

A

DRAFT TRANSLATION 579

(6)

ENGLISH TITLE: WINDOWS AS AN ENERGY FACTOR

FOREIGN TITLE: (FONSTER SOM ENERGIFAKTOR),

(10) Folke/Hagman   (11) Jan 77

(12) 64p.

AUTHOR: F. Hagman
EDITORS: W. Tobiasson and A. Greatorex

(21) Trans. from

SOURCE: Stockholm, State Council for Construction Research (Sweden)
Report R43, 1975, 71p.

rept. R43 71p 1975,

by

Translated by Rosetta Stone, Nashua, N.H. for U.S. Army Cold Regions
Research and Engineering Laboratory, 1976, 56p.

NOTICE

1473

037 100

D D C

RECEIVED

MAR 29 1977

D   B

REPORT R43: 1975

WINDOWS AS AN ENERGY FACTOR

Insulating shutters – thermal performance

Folke Hagman

CONTENTS

FOREWORD

Within the framework of research on "Windows as an energy factor",
this report analyzes the possibilities for saving energy through
"added insulation" of windows. This is assumed to be accomplished
with insulated outside shutters - a development project supported
by the Technical Development Authority, STU.

The analysis of the thermal function of windows, with and without
insulated shutters, is based on computer evaluations performed by
Dr. Engelbrekt Isfält, who has also given valuable contributions
and proof-read the manuscript.

Measurements of the insulating effect of window shutters have been
performed by the Rock Wool Inc. research facility at Skövde.

Skövde, February 1975

Folke Hagman

INTRODUCTION

Windows perform partially contradicting functions. They protect
against the environment - against changes in the climate, noise, air
pollution and intrusion. However, they also provide contact with the
environment -- letting in light, giving a view of the outdoors as well
as making ventilation and airing possible. Windows should in other
words function as controllable filters for flows of different kinds.

The supply of daylight has been the original and so far most important
function of windows. The addition of solar heat has largely been
regarded as more of a nuisance than desirable. The oil crisis has
generated an interest in the possibility of utilizing solar heat
and thereby reducing the energy needed for heated buildings. In this
context it has been suggested to use windows as "solar heat collectors"
during the day and to reduce the relatively high heat losses during
the night, e.g. by means of insulating shutters. These can also give
other advantages, such as better protection against noise.

As a background to the analysis, the thermal function of windows with
and without insulating shutters is first discussed as an introduction.
The importance for the energy consumption in a building and in the
country is illustrated by computer evaluation of different alternatives,
for different orientations (points of the compass) and latitudes.

In some respects, the evaluation must be based on partially uncertain
assumptions. This is particularly the case for the actual (average)
thermal resistance of windows and the incoming radiation with respect
to local conditions. Other uncertain factors are useful aspects in
addition to energy savings, e.g. noise suppression, the future price
of energy, future building codes and requirements on indoor climate.

The main objectives with this study were to

o survey and structure the problem complex with regard to relevant
   factors and formulated goals

o define needs for increased knowledge within the problem area

o demonstrate thermal and economical consequences of evaluated
   alternatives by means of computed examples

o give a base for technical development work.

-1-

WINDOWS AS AN ENERGY FACTOR

RADIATION DATA   SYSTEM LEVEL

a)
Solar constant   ┌─────────────┐
                                  │   SOLAR   │   SPACE
1.4 kW/m^2 │ RADIATION │
                                  └─────────────┘

b) Solar   THE ATMOSPHERE
elevation   ┌─────────────┐   ┌─────────────┐
                    │   DIRECT   │   │   SKY   │   Solar elevation
10° 0.6 kW/m^2 │ RADIATION │   │ RADIATION │   Cloud cover
45° 0.9 kW/m^2 └─────────────┘   └─────────────┘   Dust

c) Global   THE GROUND
radiation   ┌─────────────┐   ┌─────────────┐
                    │   GLOBAL   │   │ REFLECTED │   Solar elevation
10-150 kWh/m^2 │ RADIATION │   │ RADIATION │   Cloud cover
        month   └─────────────┘   └─────────────┘   Environment
                                                                  (reflections
d) DEC. | MAY   shadowing)
S   9 | 72 kWh/m2 month   ┌───────────────────────┐
F/W 3 | 78 kWh/m^2 month │ INCIDENT RADIATION   │
N   2 | 36 kWh/m^2 month │ Towards Windows   │
                             └───────────────────────┘

e)
S   360 kWh/m^2 year   ┌───────────────────────┐   THE BUILDING
E/W   220 kWh/m^2 year   │ INCOMING RADIATION   │
N   80 kWh/m^2 year   │ Through windows   │   Location
                             └───────────────────────┘   Type of windows
                                        ⊕   Window
f)   ┌──────────┐ ⊖ ┌─────────┐ ⊖ ┌──────────┐   orientation
Insulating   │   AIR   │   │ HEAT   │   │ TRANS-   │   Window
   shutters   │CIRCULATION│ │ BALANCE │   │ MISSION │   insulation
△E ≈ 300 kWh/m^2 year └──────────┘   └─────────┘   └──────────┘
                                        ⊕

                             ┌───────────────────────┐
                             │   HEAT   │
                             │   PRODUCTION   │
                             └───────────────────────┘

The diagram is designed to illustrate how solar radiation contributes to the heat supply in a building. Typical radiation data are shown to the left. Factors which influence the energy flow at different system levels are listed to the right.

COMMENTS

(a) Solar constant = the relatively constant intensity of solar radiation outside the atmosphere "on a plane perpendicular to" the direction of incidence.

(b) The atmosphere (air molecules, particles, water drops) reflect and absorb more or less solar radiation, depending on the sun's height above the horizon. The listed values refer to direct radiation (above 90 percent) + sky radiation "on a plane perpendicular to" the direction of incidence, i.e. the total radiation intensity near the surface of the earth.

(c) Global radiation = direct solar radiation + sky radiation against a horizontal surface, monthly average according to SMHI*. The range gives limiting values for most of the country during the heating season (Sept. - May). During the winter (Dec. and Jan.), up to 80 percent of the total energy flow is due to diffuse radiation. See also Table 1. On the average, the entire surface of the earth receives about 165 W/m^2.

(d) The radiation incident on a (vertical) window is determined by the global radiation reflected *from the surroundings*. The listed values are average radiation intensities at 60 degrees latitude, for different orientations and free horizon. The ground is assumed to reflect 25 percent of the global radiation.

(e) Incoming** radiation through an unprotected 2-pane window, average values for Stockholm during the heating season (Isfält, 1975). Ground reflections increase these values when the horizon is free, by 10 percent for bare ground and somewhat more for snow cover. Curtains and blinds will lower the incoming radiation considerably.

(f) The thermal balance in a building is primarily determined by heat sources (heat production + incident radiation) and heat losses (transmission + ventilation). According to this study, insulated shutters give an average heat gain of about 300 kWh/m^2 each year, see also Tables 3 and 4. As an example, for Stockholm this means a net energy gain ("positive energy balance") during the heating season (Sept. - May) for windows oriented towards the sector NE - S - NW (Figure 11).

---

*SMHI = Statens Meteorologiska och Hydrologiska Institut - the Swedish equivalent of the US Weather Bureau. (Translator's note)

** In (d), the original uses "instrålning mot", literal translation "radiation incident towards" or "incident radiation". In (e), the term "instrålning genom" means "radiation transmitted through". However, the term "transmission" is later used for energy transfer from the interior to the outside. For this reason, "incoming radiation" has been used to denote energy transmitted through the window from the outside. (Translator's note)

1. PHYSICAL BACKGROUND

1.1 Definitions and concepts

One distinguishes between direct solar radiation and diffuse radiation.
The latter consists of radiation from the sky (outside the solar disc),
as well as radiation reflected from the ground and other surrounding
objects such as buildings and trees.

Direct solar radiation and diffuse sky radiation incident on a <u>horizontal</u>
surface together make up the <u>global radiation</u>.

In the case of radiation incident on a <u>vertical</u> surface, e.g. a window,
radiation reflected from the environment is added. The global radiation
(vertical component) and reflected radiation constitute together the total
incident radiation (which is not the same as radiation transmitted <u>through</u>
the window).

The energy flux, i.e. the amount of energy per unit time, which hits a
surface perpendicular to the solar radiation <u>outside</u> the atmosphere, has
been determined experimentally. This <u>solar constant</u> has been measured
to be about 1.4 kW/m^2. The earth's atmosphere reflects and absorbs part
of the solar radiation, primarily radiation with short wavelengths
(X-rays and UV rays). The rest thus reaches the surface of the earth
in the form of direct solar radiation and - scattered by the atmosphere -
as diffuse radiation.

The <u>intensity</u> of the direct solar radiation at the earth's surface depends
on the height of the sun above the horizon, how clear the atmosphere
is and the orientation of the receiving surface (angle of incidence) In
clear weather, the direct radiation (incident on a horizontal surface)
constitutes the main energy flux, about 9/10. With average cloudcover,
the <u>diffuse</u> radiation is considerably higher than in clear weather, due
to reflections from clouds.

1.2 Daylight

The solar energy we can utilize in the form of <u>daylight</u> is a relatively
small portion of the electromagnetic radiation and ranges in wavelength
from about 0.4 μm (violet) to about 0.8 μm (red). 1 μm = 1 mikrometer =
10^{-6}m. The daylight has its maximum intensity in the 0.5 to 0.6 μm
range, i.e. in the range where the sensitivity of the eye is highest -
an example of biological adaptation and the effective utilization of the
energy by "Nature".

Intensity of solar radiation
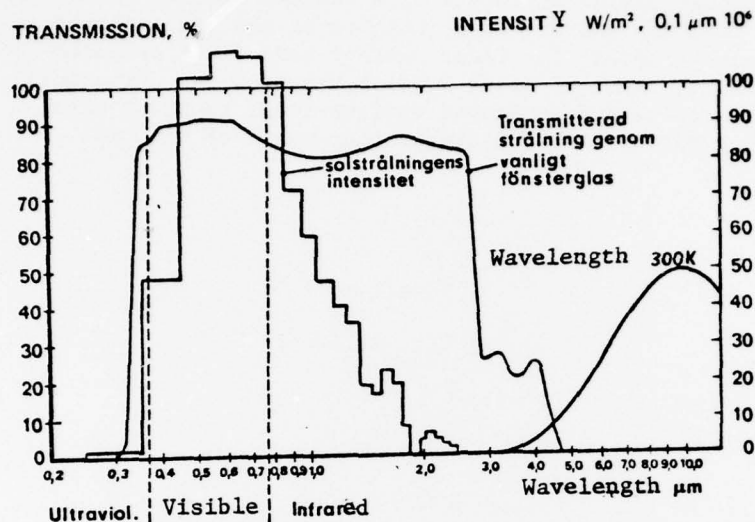
Radiation transmitted through
normal window glass

TRANSMISSION, %

INTENSITY W/m², 0,1 µm 10⁶

Transmitterad
strålning genom
vanligt
fönsterglas

solstrålningens
intensitet

Wavelength   300K

Wavelength µm

Ultraviol. | Visible | Infrared

Fig. 1   Intensity (W/m^2) of Solar radiation at different wavelengths
(per 0.1 µm). The same scale shows transmission (percent) for radiation
with perpendicular incidence on a common window pane. The curve and
horizontal scale to the right illustrate thermal radiation indoors
(black body at about 300 K). It is evident that glass will pass 80 to
90 percent of the solar radiation (about 0.3 to 3 µm) but practically
none of the long wave radiation (>3µm) reaching the window from the
inside.

1.3   Solar heat

The solar energy we can utilize in the form of heat comprises a wider
wavelength interval: about 0.4 to 2 µm. However, it is well known that
heat (thermal) radiation is emitted from the surface of any object at all
temperatures. At normal room temperature, this radiation falls mainly in
the wavelength range from 3 to 100 µm. The wavelength of maximum energy
is given by the Wien displacement law:
λ_{max} = 3000/T which for room temperature gives a maximum for λ = about
10 µm. This value, as well as the entire dominating portion of the heat
radiation, is considerably above the wavelength region, up to about 4 µm,
which is transmitted by normal window glass. In other words, the windows
function as solar or heat collectors ("green house effect").

SMHI* performs continuous measurements of the radiation which reaches the
surface of the earth. The measured parameters are global radiation and

---

* See note on page 3 .

actual <u>sunshine time</u>. Based on these primary incident radiation data, reflection properties of the ground, etc., one can calculate the total radiation incident on windows having different orientations (facing different points on the compass) and different heights of the sun (time of day, latitude). Tables and diagrams for clear weather were first prepared in our country by G. Pleijel, later by other Swedish researchers. Practical energy calculations must also take into acount various local factors, such as cloudiness, surrounding terrain and buildings, placements of windows, etc.

2. THE THERMAL PERFORMANCE OF WINDOWS

2.1 Notations and definitions

I	incoming* radiation through windows	W/m^2
t_i	indoor temperature	$°C$
t_u	outdoor temperature	$°C$
t	temperature difference $(t_i - t_u)$	K**
k	heat transfer coefficient	W/m^2K
k_t	k-value for windows, transmission only	W/m^2K
$k_{t,1}$	k-value for windows, with transmission* and air leakage through perimeter cracks taken into account	
$k_{t,1,s}$	k-value for window, with transmission, air leakage and incoming radiation taken into acount = "resulting" k-value (k_r)	W/m^2K
$E_{t,s}$	net energy flux through windows, including transmitted and incoming radiation	W/m^2
$E_{t,1,s}$	net energy flux through windows, including transmitted and incoming radiation as well as air leakage = "resulting energy flux". (E_r)	W/m^2

Note: In accordance with established definition, negative values for
k and E signify a net gain of thermal energy = positive energy
saldo *** = positive energy balance.

For k-values taking incoming radiation into account $(k_{t,s})$,
the notation "equivalent k-value" has been used,
among others by Elmroth-Höglund (1973) and Munther
(1974).

---

*   See note on page 3.
**   The original uses "K" instead of the more conventional "$°K$" to
denote "degrees Kelvin".   (Translator's note)
***   "Saldo" is a bookkeeping term, meaning "balance" or "net".
(Translator's note)

2.2 Justification for selected definitions

A number of factors contribute towards creating uncertainty regarding the functioning of windows and their importance as an energy factor. About one half of the thermal resistance is determined by the transfer resistance values on the inner and outer side ($m_i + m_y$), which in turn are affected by varying convection and radiation conditions.

One usually takes into account <u>transmission</u> only through the window itself (glass, sash and frame). <u>Air leakage</u> through perimeter cracks is regarded as "involuntary ventilation" and any such edge losses burden the transmission account of the wall.

For the total energy balance it is perhaps not important how the energy flows are separated. However, when insulating shutters are used, not only the transmission is affected (while the shutters are closed) but also losses due to air leakage. In addition, the inside surface temperature is changed, which in turn has an effect on the indoor climate.

In the following, heat transfer coefficients (k-values) are used as a unifying concept for energy flow. This is <u>done with some hesitation</u>, due to the accepted definition of k-value: "Parameter which specifies the amount of heat per hour which under stationary conditions passes perpendicularly through a square meter of a part of a structure having plane and parallel boundaries when the difference in air temperature on the two sides of the structure is 1°C. (SBN 67*)

This definition is clearly not directly suited for heat transfer through windows, where one must take into account not only transmission (by definition) but also air leakage and incoming radiation. However, nothing prevents us from defining and applying modified k-values adapted for the special thermal functions of windows.

The literature also gives some support for this (Bergvall & Dahlberg, 1944, Schule, 1962. See also Adamson, 1972, and Munther, 1974).

2.3 Transmission

The amount of transmission** loss in the window - primarily due to convection and long wavelength radiation - is determined by the surface temperatures at the boundaries as well as by the thermal resistance (M) of the window and the k-value, respectively ($k_t = 1/M$). The thermal resistance is almost entirely determined by the thermal resistance of the enclosed air layer (m_1) and the transfer resistances ($m_i + m_y$).

The effect of air layer thickness is small when this thickness exceeds about 15 mm. For a conventional two pane window with wood frame one

---

* Swedish Building Norm, 1967

** See note on page 3 .

normally uses the theoretical value $M = m_y + m_1 + m_i =$ about 0.34, which gives $k_t = 2.9$ to 3.0 W/m^{2}K. Depending on the window design and the relative ratio of glass and wood, this value can vary by one or more units in the decimal, up or down.

2.4   Perimeter losses (embrasure losses)

For windows in masonry walls, the embrasure usually results in increased heat losses due to two-dimensional heat flow (Bergvall & Dahlberg, 1944. Nevander, 1961) The magnitude of the transmission in the form of perimeter losses depends on wall material, embrasure configuration and location of the window. Embrasure losses will probably, on an average, increase the k-value of the window by 0.2 to 0.4 W/m^{2}K. For masonry walls one thus obtains k_t = 3.1 to 3.4 W/m^{2}K.

2.5   Air leakage

Wind pressure, temperature difference and mechanical ventilation, if used, will cause a pressure difference between the inside and outside of the window. The resulting air leakage through perimeter cracks depends primarily on devices for closing (locking), presence of weatherstrips and the shape stability of frames and sash. In most existing buildings, air leakage through windows provide all or much of the required ventilation. The requirement that this "involuntary ventilation" shall function even when there is no wind results in an often unnecessarily large ventilation rate on windy days. Even with more or less effective weatherstripping one will thus in practice at times suffer extra heat consumption due to excessive, cold ventilation air.

The involuntary ventilation has been investigated in Sweden in conjunction with studies of the heat balance in a few experimental houses. (A. Elmroth and I. Höglund, 1973). For wind speeds below 5 m/sec and $t_u > 0$°C the air replacement rate was found to be between 0.4 and 0.9 times per hour. The following relation has been formulated

$n = a + b\Delta t + c\,v$ replacements/hour.

The coefficients a, b, and c depend on several factors (type of house, window design, etc.). One finds that during the heating season (Δt = about 20°C, v = 3 to 4 m/sec.), temperature difference Δt and wind velocity v have about the same effect. When evaluating these results it should be kept in mind that they were obtained in special, experimental houses: "The five experimental houses were carefully constructed. Particularly in the frame house, great care was taken to achieve an airtight house".

The importance of air leakage is treated in an earlier analysis of the thermal performance of windows (Bergvall & Dahlberg, 1944). Based on

a series of laboratory tests including several frame edge designs and weather proofing materials it is summarized:

"Even a few isolated leaks can increase the k-value to 3.0 to 3.5 ($kcal/m^2h^oC$). In view of the high heat losses caused by even relatively small cracks, it is recommended that, as normal values, one uses k-values no lower than 3.0 for frame (wood) houses and 3.0 to 3.5 for masonry houses."

As a lowest value for practical application one thus recommends, 3.5 and 4.1 W/m^2K, respectively. The higher value for masonry houses is due to edge losses.

An investigation performed in Germany pertains to a larger number of standard windows, tested with respect to air leakage both before and after installation. (Schüle, 1962). For installed windows, the air leakage rate varied from 1 to 3 m^3/h per m of joint length, at a pressure difference of 1 mm water column, which corresponds to a wind velocity of about 4 m/sec. Knowing window area, length of joints (per window) and air leakage rate (per m joint) one obtains $k_{t,1}$ = 4.5 to 5.5 W/m^2K.
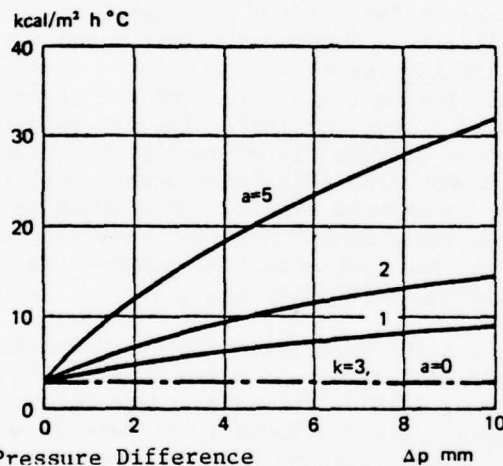

Fig. 2 Calculated heat transfer coefficient $k_{t,1}$ ($kcal/m^2h^oC$) for windows with respect to transmission and air leakage as function of the pressure difference Δp (mm water column). Joint permeability a = 1, 2 and 5 Nm^3/h.

Air leakage in windows has also been studied by the Austrian Institute for Construction Research, in connection with an extensive field survey (E. Seifert et al, 1974). This study was conducted as part of a research program with objective to study possibilities for reduction of energy requirements for heating of buildings.

During this window study, a special test method was used, developed at the Institut für Fenstertechnik (Institute for Window Technology) in Rosenheim (West Germany). The inside pressure is reduced (by means of a fan placed in an opening in the apartment door). A pressure probe is

-10-

used to register the amount of air leakage as well as variations along the joints in the window (sash/frame and frame/wall). The pressure impulses are converted to electrical voltage variations and registered in the form of flow diagrams. These allow determination of air leakage rates for different pressure differences (Δp = 15 to 60 mm water column).

Significant variations were measured, both for an individual window and between different windows. In accordance with existing codes, values for air permeability are given by the coefficient a_n ranging from 0.2 to about 7 m^3/h m $(kp/m^2)2/3$.
(kp stands for kolopond - translator's note).

To summarize, it was found that the requirements of applicable codes were not fully met for any of the windows tested (!) In several cases, new windows also gave bad results. Remarkably high leakage was further-more found between frame and wall.

A nomogram permits determination of heat loss through windows (transmission and air leakage). In one example, used to demonstrate application of the nomogram, air leakage accounts for about 42 percent of the total heat loss (window area = 2.5 m^2, Δt = 30°C, joint length 8 m, air leakage rate 2.0 m^3/m h). Converted to k-value this means an increase from about 3.0 (transmission only) to about 5 W/m^2K.

In addition to previously mentioned studies in special experimental houses, a few measurements have been made in Sweden to determine air leakage through windows (and outside walls). With assistance from the Department of Construction Technology at the Royal Institute of Tech-nology (KTH), the National Construction Board has studied air leakage in outside walls (facades) of the administration building Garnisonen (The Garrison) in Stockholm. These studies consisted of coordinated laboratory and field investigations. After careful application of V-shaped rubber weatherstrips, and with an air pressure differential of 3 mm water column (corresponding to about 6 m/sec. i.e. "moderate wind") the air leakage rate was 1.5 to 3.5 m^3/h per window, which corresponds to 0.4 to 0.9 m^3/h m (KBS* report, 1972).

2.6   Incident radiation

Radiation, in the form of direct, diffuse and reflected solar radiation, which hits a window pane, is partially reflected and the reflected portion increases with increasing angle of incidence (measured from the normal). The rest of the incident radiation is absorbed in the glass or transmitted into the building. In windows having two or more panes, this process is repeated, so that a portion of the radiation is reflected back and forth between the panes. A certain part of the energy absorbed in the glass is

_____

*KBS = Kungliga Byggnadsstyrelsen, the Royal Construction Board. (Trans-lator's note)

-11-

supplied to the room in the form of heat by means of long wavelength
radiation and convection.

Transmitted solar radiation is absorbed in (i.e. heats) surfaces and
objects indoors, which in their turn emit long wavelength radiation
that cannot penetrate the windows. There is also a heat transfer through
convection from indoor solar heated surfaces to the air in the room.

Depending on, among other things, the orientation of the windows, one
thus obtains a smaller or larger amount of added heat from the outside
during daytime hours, which can be utilized during the heating season.
The transmission factor (for solar radiation) defines the ratio between
usable solar radiation and the total incident radiation. This ratio
decreases with increasing angle of incidence as well as with increasing
number of window panes. The ratio is thus 10 to 12 percent lower for
three panes than for two (Figure 3).

In fact, the energy supplied from the outside, through windows during
daytime hours, may for most of the year be larger than the transmission
losses. This is true also during the winter season. On the other hand,
the transmission loss during the night is perhaps 5-10 times greater than
for conventional types of outside walls. The net energy transfer through
the glass in a window (taking into account transmission and radiation)
is given by

$$E_{t,s} = k_t (t_i - t_u) - I \quad W/m^2$$

The relation between solar radiation (I) and outside temperature t_u
determines whether $E_{t,s}$ is positive or negative (heat loss or
heat gain, respectively). Equilibrium (energy transfer = 0) will clearly
occur when

$I = k_t \Delta t$. If $k_t = 3.0 \ W/m^2K$; $t_i = +20^oC$, one obtains for

$t_u = -20$; $I = 120 \ W/m^2$

$t_u = 0$; $I = 60 \ W/m^2$

The incoming radiation power that is required (during daytime) to compen-
sate for transmission losses is clearly moderate and will probably be
provided by the sky radiation alone during most of the year.

The solar energy (I) supplied through a two pane window can in clear
weather amount to about 670 W/m^2 of glass surface. This value applies
in March and September when facing South and when facing East or West
during June. The maximum incoming solar radiation is thus 5 to 6 times
larger than the maximum transmission loss (about 120 W/m^2 per the
previous discussion).

A coefficient ("equivalent k-value") has been proposed, which includes the effects of both incoming radiation and transmission losses (Adamsson, 1974). The following relations are valid for this factor, here denoted $k_{t,s}$

$$k_{t,s} (t_i - t_u) = k_t (t_i - t_u) - I \text{ and}$$

$$k_{t,s} = k_t - I/(t_i - t_u) \text{ W/m}^2\text{K}$$

Let us note, that "k-values" which include a <u>radiation</u> component, such as $k_{t,l,s}$ (see 2.1) and $k_{t,s}$ in the previous expressions, relate to specified radiation conditions and are <u>average values</u>, e.g. monthly averages (normal years), for certain locations (latitude) and window orientation (towards a certain point of the compass). When multiplied by the corresponding degree-day numbers, "k-values" specified in this sense should give an approximate estimate of heating requirements for buildings.
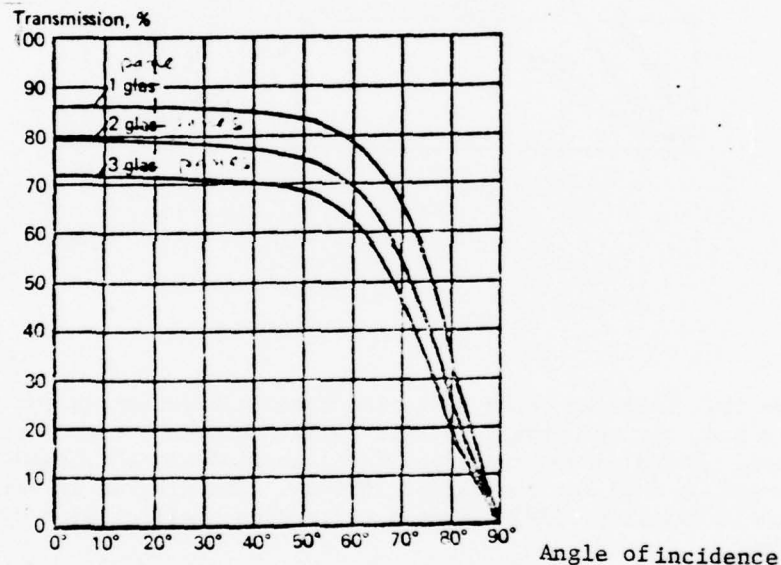

Figure 3a. Incoming solar radiation <u>through</u> windows (transmitted solar heat) for different angles of incidence and number of panes (Höglund and Ahlgren, 1973).

-13-

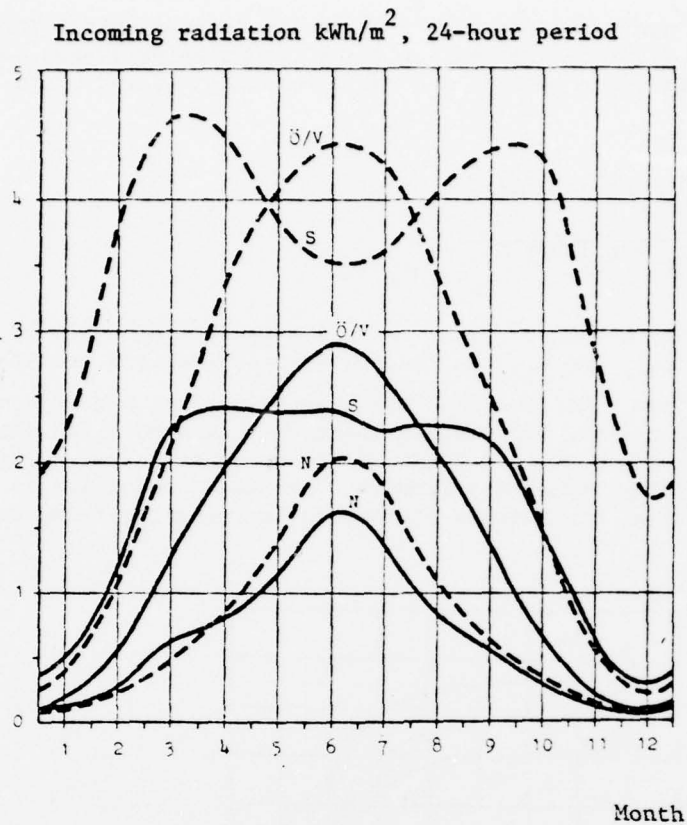Incoming radiation kWh/m^2, 24-hour period

Figure 3b. Incoming solar radiation through unprotected two pane window due to sun, sky and ground (Isfält 1975). Broken curves refer to clear weather. Solid curves represent "average conditions", based in data collected by SMHI for the period 1958-69. The diagram is valid for Stockholm (latitude 59°). Ground reflection coefficient = 0.25 is assumed.

-14-

3. INSULATING SHUTTERS

3.1 Design

In keeping with traditional types of outside, simple shutters, one can design insulating shutters to be hung from the sides, as shown in Figure 4. This type of shutters should be applicable both to new houses and to existing buildings. In the latter case there may be restrictions due to the facade configuration (adequate space must exist for the shutters when open). As an alternative one may consider sliding shutters moving either horizontally or vertically.

The thermal insulation may consist of mineral wool slabs having a sufficiently high volume weight to prevent inward convection due to winds (air permeability number <1.0 m^3/m^2 h mm water column/m).
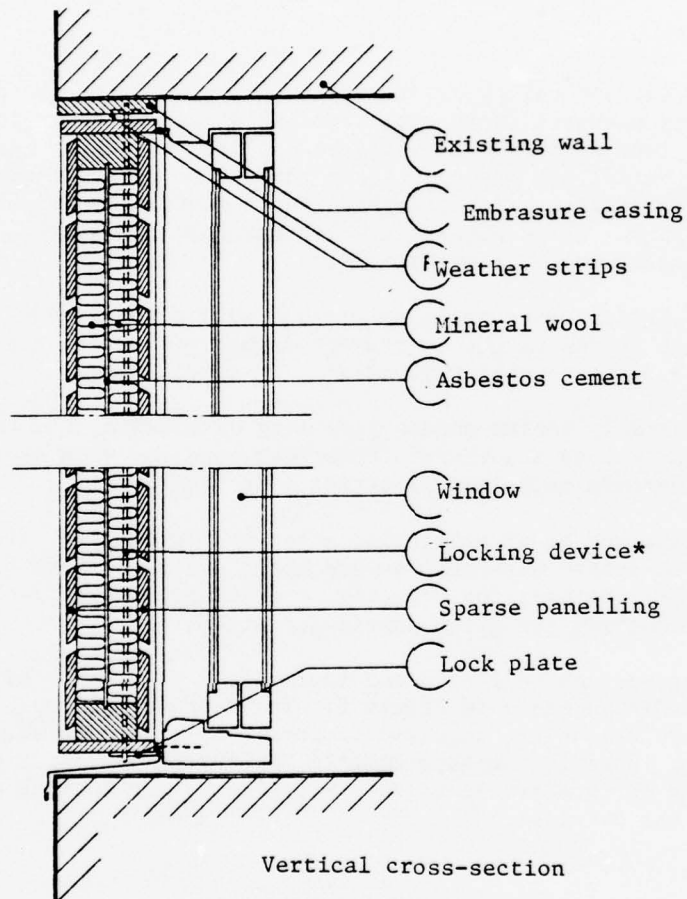
If covered by suitably spaced wooden panelling or louvers, the shutters will function as "facade absorbers" (both when open and when closed) resulting in a certain reduction in street noise level.

Frame and covering can be of a material other than wood, e.g. aluminum or plastic. Various design alternatives are being evaluated with financial support from STU*. Methods for mounting, operating, weather proofing and locking of the shutters are given particular attention.

Completed prototypes can be closed and locked from the inside by means of a "spanjolett"** as shown in Figure 5. For windows that open outwards, special design solutions are required to permit operation of shutters from the inside. However, in many cases – one story houses, windows facing a balcony or an elevated terrace – operating and locking can be performed from the outside.

---

* STU = Styrelsen for Teknisk Utveckling, a state-sponsored technical development authority. (Translator's note)

** Spanjolett is a mechanism for closing of windows, consisting of a vertical, cylindrical rod that can be rotated. The rod is placed on the outside of the window sash and its ends are equipped with claw-like extensions. When the rod is turned, these claws engage studs inserted in the upper and lower members of the window frame. (From Svensk Uppslagsbok – translator's note).

Figure 4. Labels for the vertical cross-section diagram:

- Existing wall
- Embrasure casing
- Weather strips
- Mineral wool
- Asbestos cement
- Window
- Locking device*
- Sparse panelling
- Lock plate

Vertical cross-section

*See translator's note, page 15.

Figure 4. Outside, insulating shutters. The sketch refers to shutters installed in previously built windows. (Separate installation).

-16-

**   In (d), the original uses "instrålning mot", literal translation
"radiation incident towards" or "incident radiation". In (e),
the term "instrålning genom" means "radiation transmitted through".
However, the term "transmission" is later used for energy transfer
from the interior to the outside. For this reason, "incoming
radiation" has been used to denote energy transmitted through the
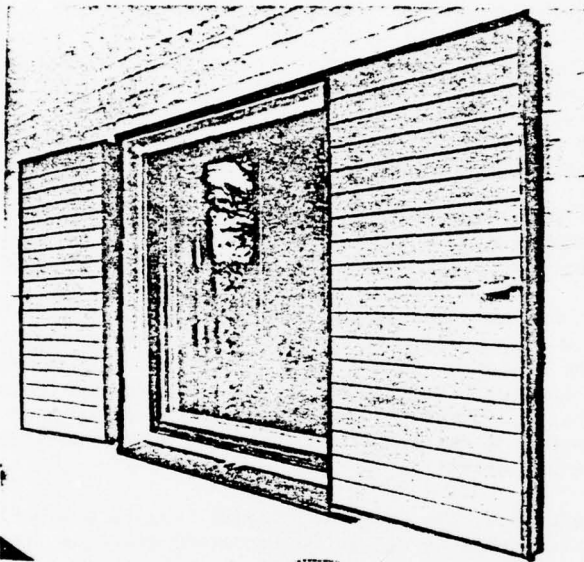window from the outside. (Translator's note)

-3-

Fig. 5a

Fig. 5b

Figure 5. Insulating window shutters. Prototypes mounted on one family
house at Skövde.

3.2 Properties

Heat and noise insulating properties of shutters with different insulation layer thicknesses have been studied by Rockwool Inc. at their research facility at Skovde. Laboratory and field prototype measurements of shutter thermal resistance indicate that one can assume $k_{t,1}$ = about 0.7 W/m^2K for a conventional 2-pane window covered by shutters having a 6 cm thick insulation layer. It is then also assumed that the shutters are equipped with weather stripping against sash and embrasure.

Laboratory measurements have shown that the sound insulation of a conventional 2-pane window can be improved from about 20 dB to approximately 37 dB (average attenuation for the frequency range from 125 to 5000 Hz).

Approximate calculations show that if the shutters are built with "spaced"* panelling as discussed previously, the noise level in the street is reduced. For a main street, the reduction is 2.5 to 3.5 dB (0 and 27 m above street level, respectively) and for a side street 6-9 dB (distance to main street 40 and 180 m respectively). A reduction of the noise level by 5 dB corresponds to a lowering of the experienced noise disturbance (subjective noise level) by about 25 percent.

For comparison and reference, the following values have been established for reduction of traffic noise level due to increased distance from a major highway:

$50 \rightarrow 80$ and $100 \rightarrow 150$ m = 3 dB

The effect of reduced driving speed:

$90 \rightarrow 70$ km/h = 3 dB

Reducing the traffic volume by a half also gives a noise reduction of about 3 dB.

In addition to the primary insulating functions already mentioned, it should be noted that shutters give increased possibilities for sun protection and black-out, as well as for improved burglar and fire protection (fires often spread through windows). Suitably designed, the shutters should also be able to serve as an architectural form element.**

---

* Original uses the word "gles", meaning sparce, far between, etc. In this context, the word implies that the boards on both sides of the shutters are spaced some distance apart, c.f. Figure 4. (Translator's note)

** I.e., give architects another degree of freedom when designing for appearance. (Translator's note)

3.3   Thermal performance

3.3.1 General conditions

In defining k-values for windows, one normally does not consider <u>air leakage</u> and edge <u>losses</u> (nor incoming radiation). However, see Shüle as well as Bergvall and Dahlberg. When calculating the thermal performance of insulating window shutters, one could justify taking into account the total insulating effect, for the following reasons:

A/ During windy weather and particularly when the outside temperature is low, air leakage through windows may require a relatively high extra power, with a corresponding increase in energy consumption. To counteract draft from windows one may also increase the room temperature.

B/ Even when weather strips are used it is in practice difficult to obtain the desired performance (correct rate of air exchange). This is, among other factors, due to difficulty in matching the locking pressure to the dimensions of the weather strips, aging and other material properties.

C/ Window shutters can be made air tight by employing weather strips against the outer frame or embrasure casing, as well as against the existing window frame, i.e. in three planes. Thereby, both air leakage and edge losses are affected. This extra insulation and air leakage reduction is of course particularly important during windy and cold weather.

3.3.2 Effects on heat consumption ($k_{t,1}$)

Through measurements it has been found that air leakage through windows can vary widely, for 1 mm water column, from about 0.05 to 10 m^3/h m depending on window design and weather stripping (Rydberg, 1969). If the heat required to maintain room temperature in the presence of air leakage is included when the k-value is determined for a window, one obtains for a 2-pane, 1.4 x 1.4 m square window a variation in the range 3 $<k_{t,1}$ < 15 W/m^2K.

The reduction in air leakage due to shutters depends of course on the leakage through the window itself and will thus vary considerably. A cautious and perhaps realistic estimate of the improvement can be made based on the normally assumed rate of air exchange, 1 exch/h. In existing houses, the value is probably often higher. "Expressed in terms of air exchange rate, the so called involuntary ventilation due to air leaks is in the order of 0.3 to 0.6 exchanges * (referred to the entire building volume) in new houses. In older buildings this ventilation is higher, often twice as high or more" (SOU 1975:76).**

---

* No time period is given in the original, but 1 hour is probably implied. (Translator's note)

** Information concerning this reference has been requested from the author. (Translator's note)

Thus, assume 1 exch/h and that half of the exchanged air is supplied in the form of involuntary ventilation through windows. For a room having a volume of 60 m^3 this means that the windows contribute 30 m^3. If the window area is 4 m^2 and the air leakage is included, we obtain for a 2-pane window

$$k_{t,1} = 3.0 + (30 \times 0.36/4) = 5.7 \text{ W/m}^2\text{K}$$

In order not to overestimate the improvement that shutters can give, we conservatively select $k_{t,1}$ = 4.0 for 2-pane windows without shutters as a reasonable, average value for existing residential houses.

If we assume k_t = 3.0 for the window itself (without air leakage), we find that $k_{t,1}$ = 4.0 implies an air leakage of about 0.2 exch/h for the room in the previous example. It is thus assumed that the shutters will decrease the air exchange by this value, i.e. from 1.0 to 0.8 exch/h.

For new, well-weatherproofed windows, one can probably assume $k_{t,1}$ = k_t = $\underline{3}$ W/m^{2}K.

3.3.3 Effects on room climate

The room climate is determined by thermal and lighting conditions, by humidity and other properties of the air, ventilation, etc. Both the temperature of the air and of enclosing surfaces affect the heat comfort. Interior surface temperatures of walls, windows, etc., are given in terms of their "radiation temperature". This term alludes to the heat loss a person experiences in the directions toward colder surfaces, which may give rise to feeling of "draft", e.g. from windows even if they are air tight.

The concept of "operative temperature" has been introduced as an overall measure of heat comfort. This temperature is approximately equal to the average of air and enclosing surface temperatures. During the cold season, the temperature on the inside of outer walls and windows is lower than for other room surfaces. The operative temperature will then be different in different directions and be lower in the direction of a wall with windows. However, a physiological condition for heat comfort is a reasonably equal distribution of heat flow from the body.

In a proposed code under preparation by the Construction Department of the State Planning Board it is suggested that the highest allowed value of the operative temperature shall be 18°C in dwellings, 20°C in day care centers for children, in old people's homes, etc. It is also proposed that the highest variation in "directed" operative temperature towards different enclosing surfaces shall be 4°C.

The operative temperature (t_{op}) is determined as the average of the room air temperature (t_i) and the "mean" radiation temperature ($\bar{t}_s$) for

-20-

enclosing surfaces located within a half sphere having its center at a
point within the "dwelling zone" in the room. When the interior surface
temperatures (t_o) of all enclosing surfaces are known, $\bar{t}_s$ for a desired
point is obtained with the aid of solid angle coefficients (φ), for
which diagrams are available.

The following relation applies

$$t_{op} = \frac{t_i + \bar{t}_s}{2} \quad {}^{\circ}C$$

$\bar{t}_s = \Sigma \varphi t_o$, for all enclosing surfaces (walls, windows, floor, ceiling).

Specified maximum values for operative temperature is primarily checked
at the most exposed points within the dwelling zone in a room, i.e. normally
1 m perpendicularly away from the center points of windows. For outer
walls with windows, the dwelling zone is assumed to extend to 1 m from
the wall. For walls without windows, the bordering plane is assumed to
be 0.5 m away from outer walls.

A number of temperature measurements have been performed to determine
the effect of insulating shutters on the surface temperatures of windows.
These measurements were made on "single luft"* windows with outside
dimensions 1150 x 1250 mm (including the frame). The shutters were
insulated with 50 mm thick mineral wool and designed as shown in Figures
4 and 5. The internal surface temperature (t_f) was measured at the center
of each window, using a thermoelectric surface temperature gauge. The
radiator below the window was either turned on, Figure 6, or turned off,
Figure 7.

As shown in the diagrams, t_f is significantly reduced when the shutters
are opened, but increases again when they are closed. Cooling down of
the window after opening the shutters took about 1 hour. The warm-up time
following their closing was about 2 hours. The measured results are
summarized in the table

Radiator setting	Heat on			Heat off		
Temperature ${}^{\circ}C$	t_i	t_f	$t_i - t_f$	t_i	t_f	$t_i - t_f$
Shutters open	20-20.5	12.5	7.5-8	19.5	12.5	7
Shutters closed	≈ 20	17.5	2.5	19.5	15.5	4

* Single "luft" refers to windows in which the glass panes extend across
the entire area.

The temperature with closed shutters is thus increased by about $\underline{5^oC}$ when the radiator is on and by about $\underline{3^oC}$ when it is off. $\underline{Calculation}$ of t_f according to the proposed code $\overline{(m_i = 0.12,\ m_u = 0.05\ m^2\ \ ^oC/W,}$ $t_i = 20,\ t_f = 13^oC)$ and with the thermal resistance for windows + shutters = 1.43 ($k_{t,\ 1} = 0.7\ W/m^2K$) gives good agreement with $\underline{measured}$ data for the case when the radiator is on. One obtains

Measured temp. diff. $t_i - t_f$ = about 5^oC

Calculated temp. diff. $t_i - t_f$ = 5.3^oC

For a lowest design temperature of -22^oC, one obtains for the case with the radiator off

Window alone $t_f = +5.2^oC$

Window + shutters $t_f = 16.5^oC$

Insulating shutters can thus increase the temperature at the inner surface of the window by up to 10^oC ($t_u = -22^oC$). The operative temperature is then increased and made more even, which has a beneficial effect on the room climate. This is of course true only when the shutters are closed, normally during the dark part of the day. The improved room climate will also make it possible to extend the "dwelling zone" in the apartment. Also during the winter one can, without discomfort, stay less than 1 m from windows. It would be interesting to clarify whether this effect on the room climate can influence floor plan designs as well as design values for heating power requirement and energy consumption.
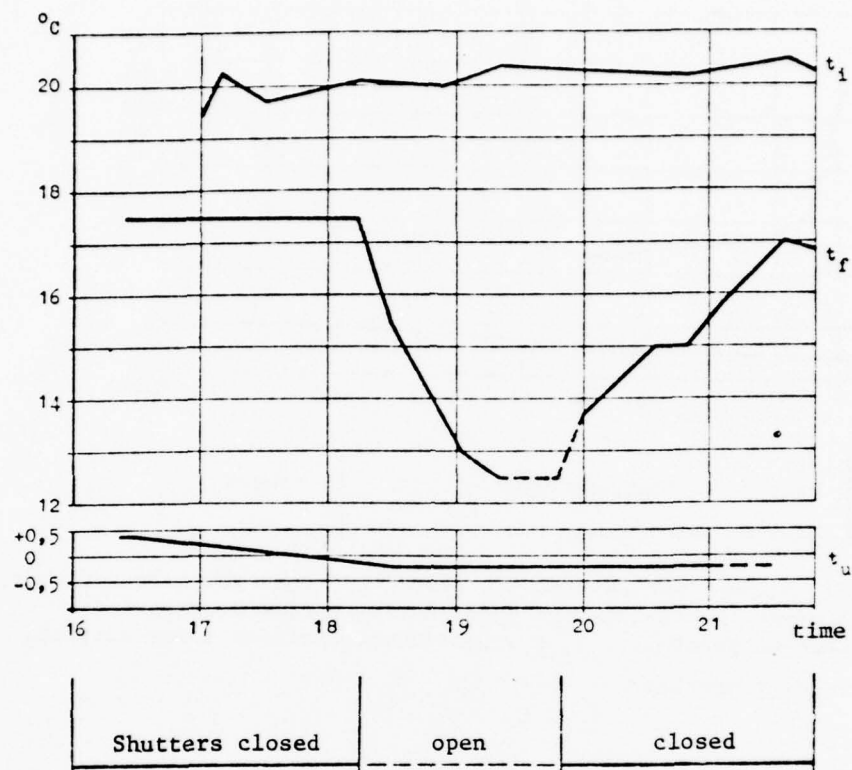
Figure 6. Window temperature with closed and open shutters. Field measurements on window with shutters as shown in Figure 5a. Cloudy, weak wind. Radiator below window <u>turned on</u> during entire test cycle. t_i = indoor temperature, t_f = window temperature on inner surface, t_u = outdoor temperature.

-23-

°C 20

18

16

14

12

4
2
0

kI   8   9   10   11   12   13   14   15   16   17   18   19   time

t_i
t_f
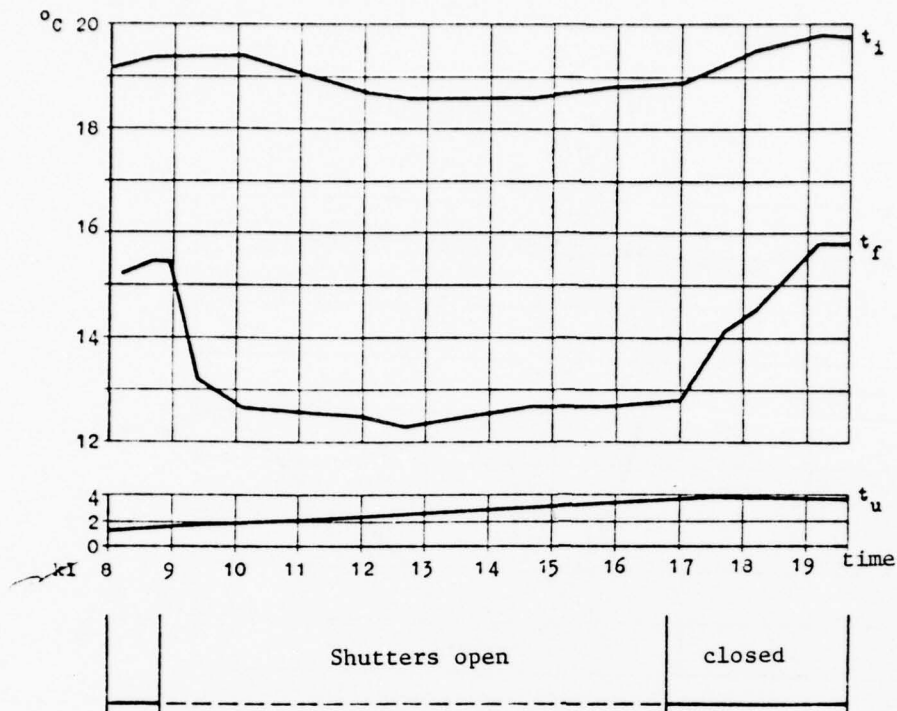t_u

Shutters open   closed

Figure 7. Window temperature with closed and open shutters. Cloudy, wind 2-3 m/sec. Radiator __turned off__ during entire test period. t_i = indoor temperature, t_f = window temperature on inner surface, t_u = outdoor temperature.

4. COMPUTER EVALUATION OF INCOMING RADIATION THROUGH WINDOWS

4.1 General conditions

Computer programs used to date in our country for determining incoming radiation through windows have been used to establish cooling* requirements and thus adapted for __clear weather__. However, in the present case, the __average radiation__ from sun, sky and ground is of interest.

The main objective is to determine the average, total incoming radiation transmitted through the windows (the sun catch**) per square meter (glass area) and month. This is done, based on values computed for every half hour of the 15th day*** in each month.

---

*   Or rather air conditioning requirements. (Translator's note)

**   Literal translation, for what it is worth. (Translator's note)

*** The original uses the word "dygn" = "24 hour period". (Translator's note)

-24-

Primary radiation data, i.e. average total solar radiation
(global radiation) is obtained from the data measured by SMHI, which
also include total sunshine time. Other primary parameters to consider
are orientation of the windows (points on the compass), latitude,
reflection properties (the environment) and transmission properties of
the window.

In practice, windows are often shadowed, partially and part of the time,
e.g. by balconies or surrounding walls. (Höglund and Åhlgren, 1973).
Nearby buildings may also have a shadowing effect, particularly in densely
built areas and during the winter (when the sun is low above the horizon).
This kind of shadowing, which can vary considerably, is normally neglected
in computer calculations, i.e. the horizon is assumed to be free.

To evaluate the thermal performance of windows with respect to possible
contributions from solar heating, it is necessary to take the effect of
shadowing into account. For the case at hand, where the effects of
shutters is to be determined, shadowing is probably of minor importance
and mainly implies that the shutters are kept closed during a somewhat
longer time. This is at least true during the winter and in rooms and
apartments where nobody is present during the day. From a thermal point
of view this implies an additional decrease of the transmission losses.

The computer evaluations consist of the following steps:

o Astronomical data (declination and time equation) are determined from
   the date. Values for these parameters are for example listed in the
   Swedish almanac. For computer analysis they can be expressed with
   sufficient accuracy by means of Fourier series having six terms.

o The direction towards the sun in elevation and azimuth can then be
   determined from trigonometric expressions which also contain longitude,
   latitude and time of day.

o The direction towards the sun is determined in relation to the orientation
   (point of the compass) of the irradiated window surface.

o The intensity of the solar radiation is calculated (for a plane perpendi-
   cular to the direction of radiation). Diffuse sky radiation towards a
   horizontal surface is determined. In either case, the radiation depends
   on the height of the sun above the horizon and the calculations are based
   on empirical data.

o The (vertical) components of the global radiation are calculated for the
   actual window area.

o The direct solar radiation through the window is computed, based on
   angle of incidence and transmission factor. Transmission of diffuse
   radiation - both in clear and cloudy weather - is assumed to be indepen-
   dent of the position of the sun (angle of incidence).

o Transmitted radiation from sun, sky and ground are summed. This is done
   for every half hour on the 15th day of each month.

-25-

4.2   Average incoming radiation

The incoming radiation calculated for clear weather must be reduced
in proportion to actual hours of sunshine. This is done by means of a
factor, defined as the ratio between actual sunshine hours, measured by
SMHI and astronomically possible sunshine hours. The sky radiation
computed for clear weather is then corrected so that the global radiation
agrees with measured values.

Table 1. The table shows the result of a separation between direct solar
radiation and global radiation (according to SMHI), for Malmö, Stockholm
and Luleå. For comparison, the global radiation calculated for clear
weather is also included. The calculations apply to the 15th of each month.

Average, monthly incident radiation towards a horizontal
surface, Wh/m^2, 24-hour period.

Month	Malmö			Stockholm			Luleå		
	Direct sun[a]	Global radia		Direct sun[a]	Global radia		Direct sun[a]	Global radia	
		Actual[c]	Clear[b]		Actual[c]	Clear[b]		Actual[c]	Clear[b]
1	100	440	890	70	350	480	10	130[d]	60
2	390	1010	2080	350	930	1550	120	690	810
3	1080	2320	3890	1120	2410	3360	820	2060	2540
4	2150	3760	6180	2290	3700	5790	1900	3440	5150
5	3450	4900	7710	3450	4980	7490	2690	4890	7160
6	3690	5910	8640	4140	5990	8550	3200	5560	8450
7	3420	4950	8260	3700	5300	8120	3250	5260	7920
8	2620	4070	6740	2780	3980	6420	2020	3420	5910
9	1700	2930	4610	1520	2630	4130	1040	1930	3380
10	580	1460	2760	580	1180	2220	360	730	1410
11	140	540	1220	110	410	760	30	190	220
12	50	290	650	30	210	290	0	30[d]	10

[a] Calculated portion due to direct solar radiation, based on data for
actual sunshine hours.

[b] Calculated for clear weather = direct solar radiation + diffuse sky
radiation for each latitude.

[c] SMHI monthly data divided by number of days in the month.

[d] Due to the low sun position above the horizon, the direct radiation
towards a horizontal surface becomes small. The sky radiation is in
clear weather lower than with average cloud cover. For these reasons,
the global radiation is higher for average conditions than in clear
weather.

-26-

4.3   Evaluated cases

4.3.1   Notations and conditions

A_f window area, including frame m^2

A_g glass area = area that tramsmits radiation m^2

^oD degree days, climate factor = heat requirement per
         month for a certain location = the sum (over the
         month) of the difference $t_i - t_u$ multiplied by the
         number of days in the month ^oC days/month

Q heat consumption factor = degree day factor
         multiplied by number of hours per day divided by
         10^3 ^oC h 10^{-3}/month

N number of days per month

n_f time, windows exposed   h/day

n_1 time, shutters closed   h/day

Q_f heat consumption factor, exposed windows ^oC h 10^{-3}/month
         $(^oD\ n_f)$

Q_1 heat consumption factor, closed shutters ^oC h 10^{-3}/month
         $(^oD\ n_1)$

In calculating transmission losses through windows one should consider
that radiators are usually placed below windows. Along the surface of
the window there is thus an air stream with a temperature somewhat higher
than that of the room air. To account for this condition we select

$t_i = \underline{22^oC}$

In accordance with the previous discussion (3.3) we choose, as average
values applicable to practical cases:

for 2-pane windows in existing buildings $k_{t,1} = \underline{4.0}$ W/m^2K

for new, well weatherstripped 2-pane windows $k_{t,1} = k_t = \underline{3.0}\ W/m^2K$

for 2-pane windows with insulating shutters $k_{t,1} = \underline{0.7}\ W/m^2K$

-27-

Note: k-values pertaining to transmission and air leakage are referred
to total window area (A_f). Calculated transmitted* solar radiation and
its share in resulting k-value ($k_{t,1,s}$) is based on glass area (A_g).

4.3.2   Evaluated alternatives

Computer calculations give the <u>net energy flow</u> ("energy balance"), i.e.
the sum of transmission losses and <u>total incoming radiation</u> through the
window in kWh/month, kWh/year and m^2 (A_g), respectively.

The calculations pertain to Malmö, Stockholm and Luleå, as well as eight
window orientations (N – NE – E – SE – S – SW – W – NW) and the following
design alternatives:

Alt. 1. Window shutters <u>always closed</u> (no incoming radiation). From an
         energy standpoint this corresponds to a wall with the same thermal
         resistance as windows + shutters, i.e. $k_{t,1}$ = 0.7 W/m^2K, which
         approximately equals the average value for outer walls in
         existing buildings.

Alt. 2. Shutters <u>never closed</u> (decorative function only), $k_{t,1}$ = <u>4.0</u>
         or alternately 3.0 W/m^2K.

Alt. 3. Shutters <u>closed "at night"</u>. More precisely, the shutters are
         open from 8 AM to 10 PM, when there is a chance to receive
         solar radiation (when the sun may illuminate the facade).
         With this assumption, the shutters may be open also during
         times when the heat losses exceed the heat gain due to incoming
         radiation.

Alt. 4. Shutters closed when energy savings results (net energy flow
         $E_{t,1,s}$ > 0). In other words, the shutters are open <u>when energy
         can be gained</u>, i.e. when the energy balance is negative. From
         an energy economy point of view this implies optimum use of the
         shutters. The resulting k-value for the windows, $k_{t,1,s}$ is then
         always <0.7 (closed shutters).

4.3.3   Resulting energy flow

The amount of incoming solar energy transmitted through the window (I)
is based on a calculation of total incoming radiation during the 15th
day of each month. We denote this 24-hour average value $\bar{I}$. For alter-
natives 3 and 4, when the shutters are closed during the night, the net
or resulting energy flow is obtained from

$$E_r = E_{t,1,s} = \underbrace{k_{t,1} \ (t_i - t_u) \ n_1 N}_{\text{night}} + \underbrace{k_{t,1} \ (t_i - t_u) n_f N}_{\text{day}} - \bar{I}N \quad Wh/m^2 \text{ month}$$

---

* i.e. incoming (Translator's note)

Note: According to the assumption, the values of $\overline{I}$ are somewhat different for alternatives 3 and 4. Also, the value of t_u during the night differs somewhat from the value during the day and from the 24-hour mean. The night temperature has been assumed to be 1°C lower than the 24-hour mean.

With assumed values one obtains

$$E_r = 0.7 \ (22-t_u) \ n_1 N + k_{t,1} \ (22-t_u) \ n_f N - \overline{I}N \ \text{Wh/m}^2 \ \text{month}$$

For <u>alt. 1</u> (shutters always closed), the 2nd and 3rd terms are omitted.
For <u>alt. 2</u> (shutters never closed), the 1st term is omitted.

In the computer calculations, energy flows are integrated according to the rules that apply to each alternative.

Table 2 summarizes results from computations assuming $k_{t,1} = 4.0$ for windows alone (alt. 2.). The corresponding diagram in Figures 8, 9 and 10 show the energy flow by month. Table 3 shows the energy flow when the k-value for windows is 3.0 W/m²K (relatively new, well-weatherproofed windows).

Table 2. Resulting energy flow in kWh/m² (glass area) for the period September – May for alternatives 1 – 4, from computer calculations. Window k-value = 4.0 W/m²K. <u>Positive</u> values signify <u>loss</u> (heat deficiency) while <u>negative</u> values imply <u>heat gain</u>.

Location	Alt.	N	NE/NW	E/W	SE/SW	S
Luleå	1	115,0	115,0	115,0	115,0	115,0
Luleå	2	556,6	524,3	440,7	354,1	319,1
Luleå	3	115,3	118,7	87,6	13,2	-41,9
Luleå	4	107,6	81,4	14,4	-51,5	-75,8
Stockholm	1	90,1	90,1	90,1	90,1	90,1
Stockholm	2	412,3	370,9	267,9	166,1	127,9
Stockholm	3	92,1	88,8	29,7	-68,2	-133,1
Stockholm	4	79,3	45,1	-42,8	-123,9	-152,1
Malmö	1	81,5	81,5	81,5	81,5	81,5
Malmö	2	358,1	318,2	222,9	136,1	109,0
Malmö	3	84,7	75,3	9,8	-76,7	-121,6
Malmö	4	66,1	31,8	-49,8	-119,2	-139,3

Table 3. Resulting energy flow in kWh/m^2 (glass area) for the period September – May for alternatives 2 and 4, from computer calculations. Window k-value = 3.0 W/m^{2}K. <u>Positive</u> values signify <u>loss</u> (heat deficiency) while <u>negative</u> values imply <u>heat gain</u>.

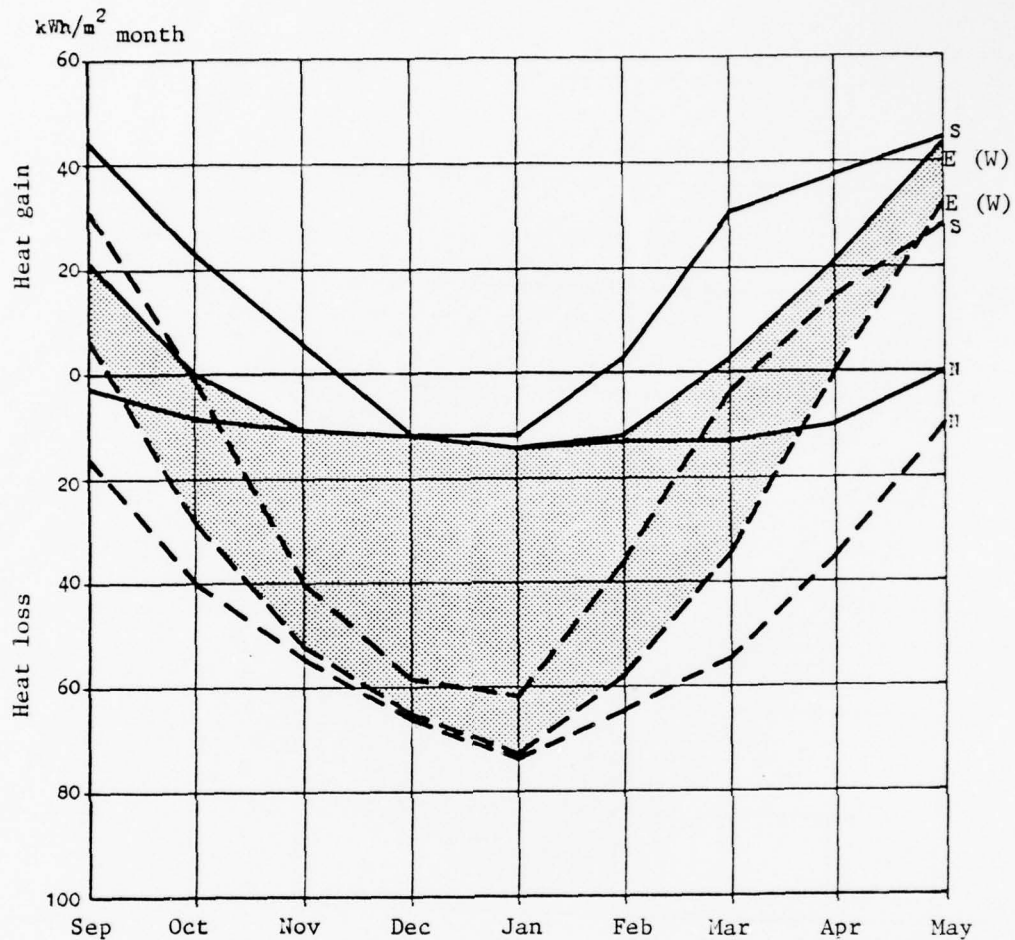| Location	Alt.	N	E/W	S
Luleå	2	392,3	276,4	154,8
Luleå	4	95,5	-8,4	-112,0
Stockholm	2	283,6	139,4	-1,1
Stockholm	4	65,1	-66,0	-189,2
Malmö	2	241,4	106,0	-7,6
Malmö	4	49,3	-74,2	-175,2

kWh/m^2 month

Figure 8. Energy balance for 2-pane windows, including transmission,
air leakage and incoming radiation (E$_{t,1,s}$), from computer calculations.
Solid curves: with shutters (optimum utilization = alt. 4) Broken curves:
without shutters (alt. 2). The values apply to Stockholm (latitude 59°).
Compass points N, S, E (W). Shaded area = energy gain with shutters,
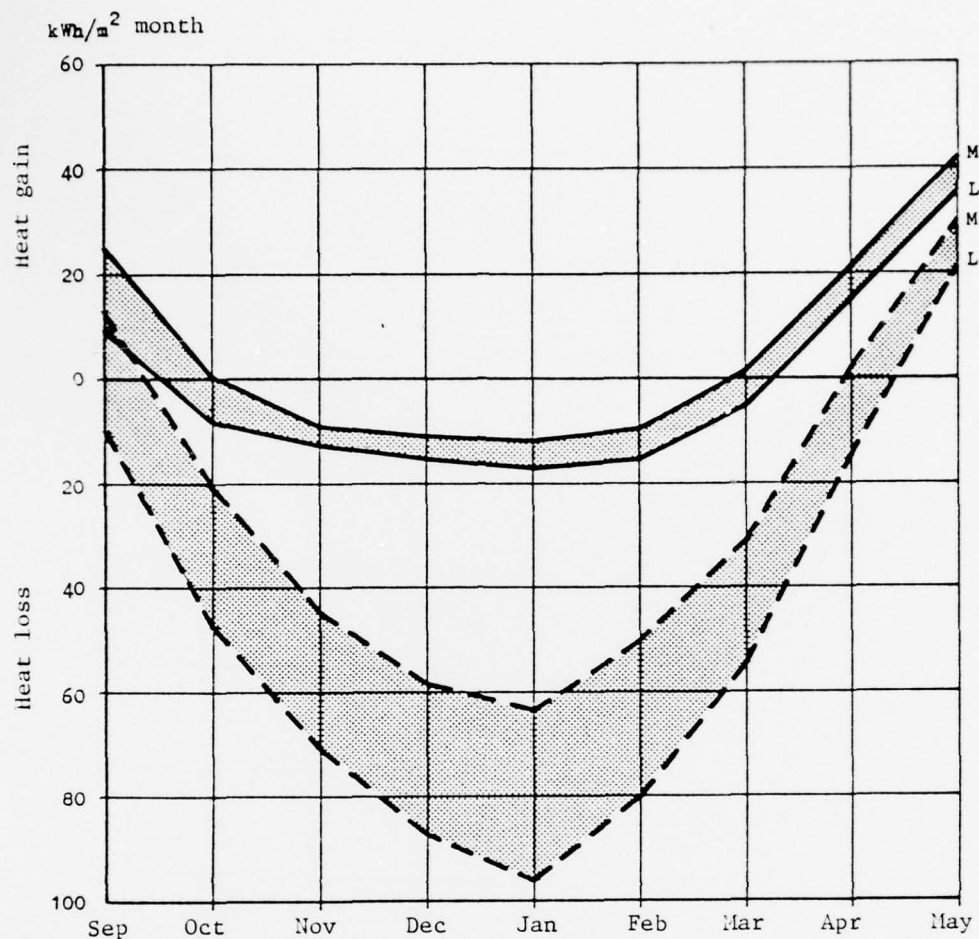facing E (W).

Figure 9. Energy balance for 2-pane windows, including transmission, air leakage and incoming radiation ($E_{t,1,s}$), from computer calculations. <u>Solid</u> curves: with shutters (optimum utilization = alt. 4). <u>Broken</u> curves: without shutters (alt. 2). The curves are valid for Luleå (L) and Malmö (M), compass point E (W). Shaded area = difference in energy needs Luleå - Malmö, <u>with</u> and <u>without</u> shutters, respectively.
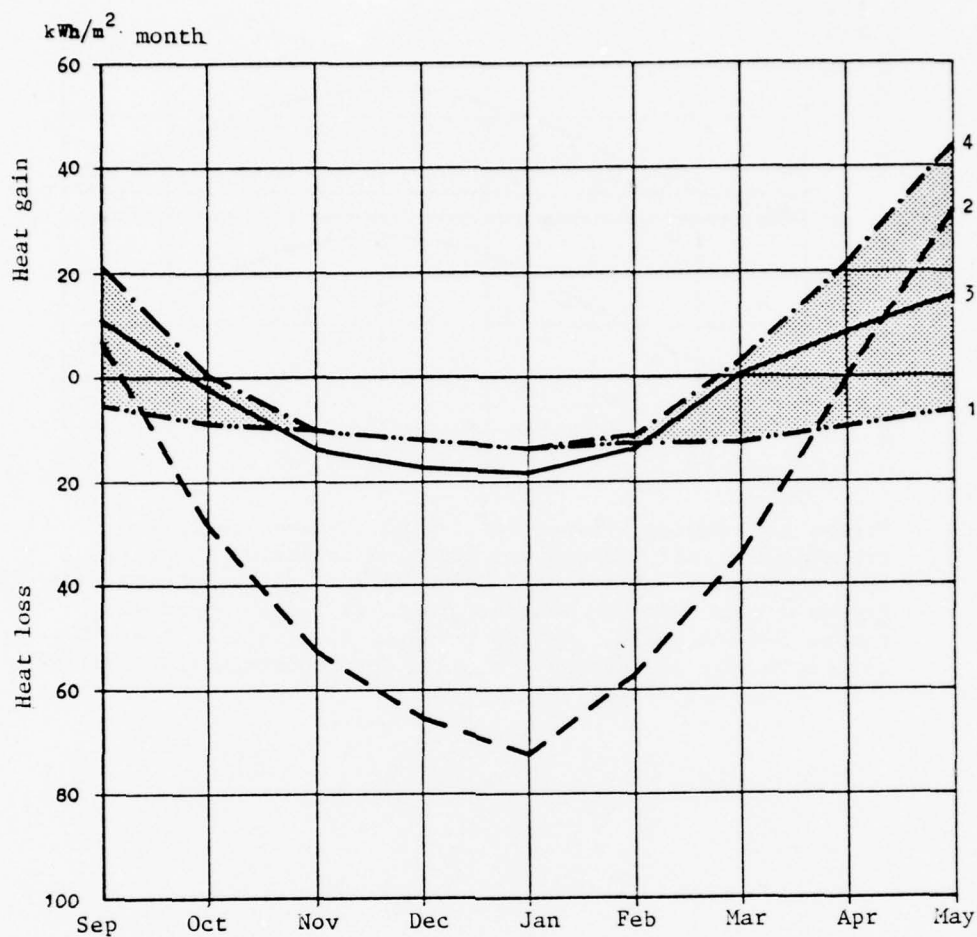
Figure 10. Energy balance for 2-pane windows, from computer analysis
of different alternatives. 1 = shutters always closed (k = 0.7 W/m²K),
2 = only 2-pane windows, 3 = shutters closed "at night", 4 = shutters
utilized in optimum fashion. The curves are valid for Stockholm,
compass point E (W). Shaded area = energy gain with shutters (alt. 4)
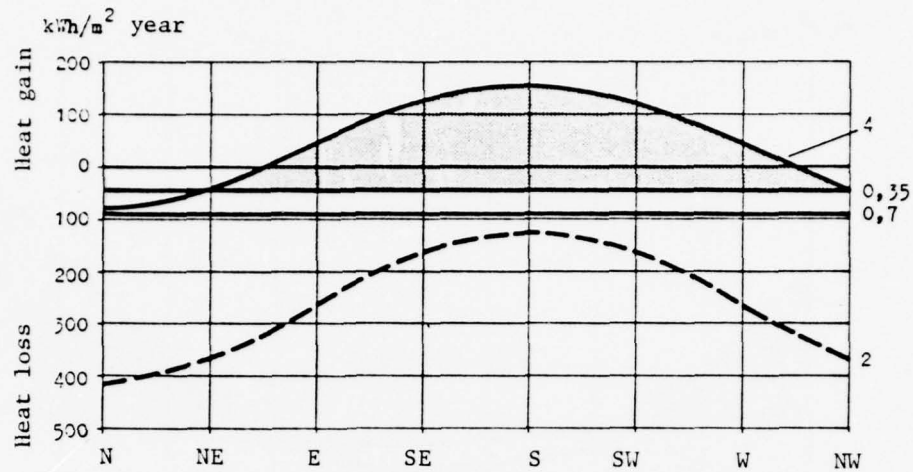compared to wall with k = 0.7 (alt. 1).

-33-

Figure 11. Energy balance for 2-pane windows, including transmission, air leakage and incoming radiation ($E_{t,1,s}$) from computer calculations. Solid curve: <u>with</u> shutters (alt. 4). <u>Broken</u> curve: without shutters (alt. 2). Also shown are curves for two <u>walls</u>, having k-values = 0.7 and 0.35 W/m^{2}K respectively. All curves are valid for Stockholm (latitude 59°) and the heating season (Sept. - May).

For example, Figure 15 shows that for E_p = 10 one obtains, for windows

4.4   Summary and conclusions

Table 2 and Figure 11 illustrate the effects of <u>window orientation</u> and <u>shutters</u> on the energy balance of windows. As an example, the total energy loss for windows only, $k_{t,1}$ = 4.0 (alt. 2) and facing <u>north</u>, is more than three times higher than for windows facing south (412/128). Also with shutters (alt. 4) there is some loss for windows facing north (79), but gain when facing south (152). Alt. 4 gives heat gain for Stockholm and Malmö in all directions except NE/NW and N.

From Table 2 and Figure 11 it is clear that alt. 4 (shutters), facing any point of the compass, is more advantageous than alt. 1 (wall: k = 0.7), which in turn is better than alt. 2 (windows only). These relations do not change significantly if the k-value for alt. 1 is lowered from 0.7 to about 0.35 W/m^2K. It should be added that this conclusion applies to thermal considerations only.

From an energy economy point of view, it turns out that the shutters should be closed (even when facing south) during December in Malmö and Stockholm, but in Luleå also during November and January.

In addition to monthly values for net energy flow, the computed results include specific flow values* for each alternative and compass point, i.e. resulting k-values (monthly averages). For alt. 1, as well as for alt. 3 and 4 when shutters are closed, the assumed conditions give $k_{t,1} = k_r$ = 0.7 W/m^2K. For other cases, the value of k_r varies from +4.0 (Luleå, alt. 2, in December) to -6.8 W/m^2K(Malmö, alt. 4, facing south, in September).

Figure 12 shows "resulting k-values" for Stockholm, in February and April and for calculated alternatives and compass points.

----

* "Spec." in the original means "specific" in the sense of energy flow per unit area (m^2). C.f. "specific weight" for "weight per unit volume". (Translator's note)
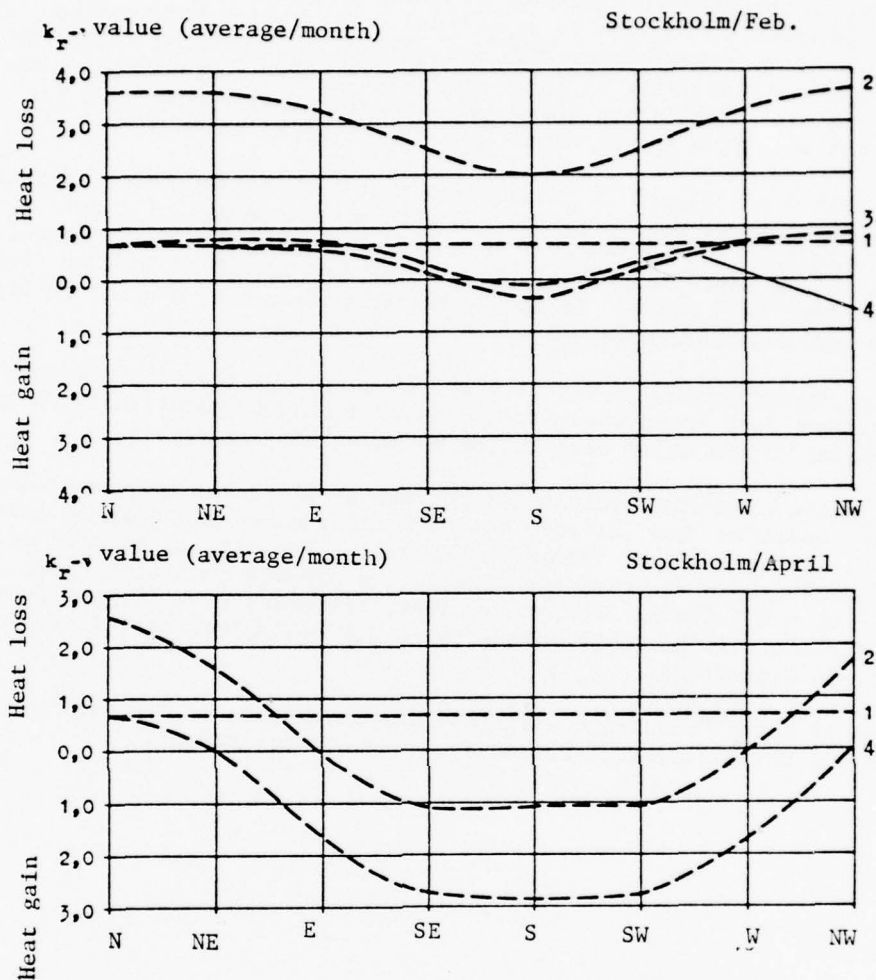
Figure 12. "Resulting k-values" (W/m^2K) for computed alternatives (1-4). The curves show monthly averages $(\bar{k}_{t,1,s})$ in Stockholm for February and April, respectively.

Figure 13 shows the effect of the k-value of a window on the energy balance. The diagram is valid for Stockholm and windows facing east/west. It can be seen that the difference between curves for k = 4.0 and 3.0 W/m²K is small, particularly during the winter months and when shutters are used (alt. 4). Without shutters (alt. 2), a k-value of 3.0 results in a gain of 25 to 30 percent, as compared to k = 4.0.
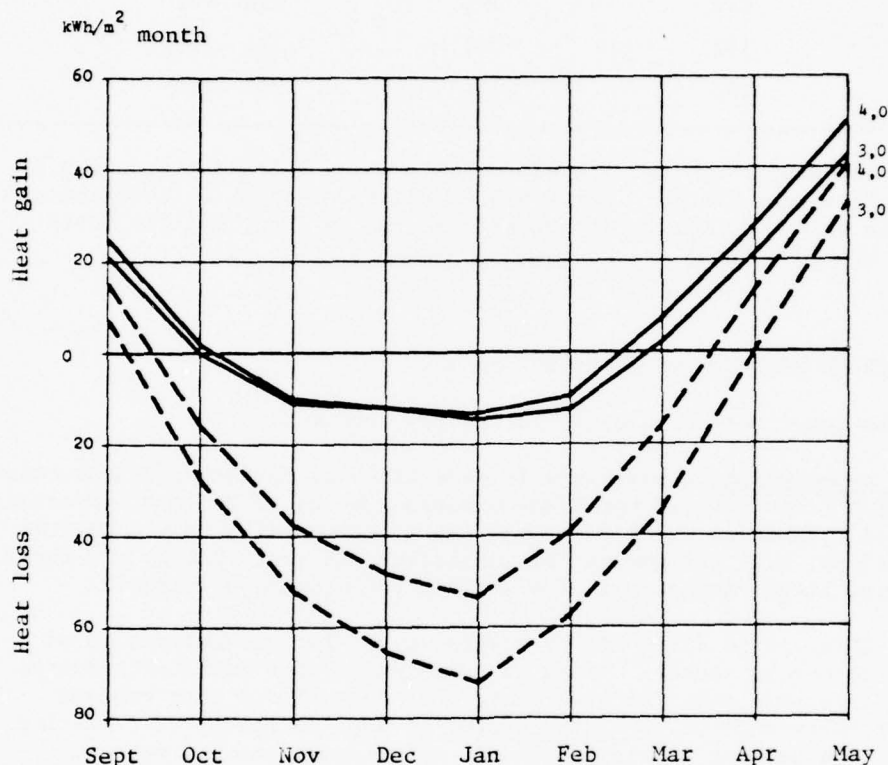

Figure 13. Energy balance for 2-pane windows, including transmission, air leakage and incoming radiation, from computer calculations. Solid curves: with shutters (alt. 4). Broken curves: without shutters (alt. 2). The k-value for the window (no incoming radiation): $k_{t,1}$ = 4.0 and 3.0 W/m²K, respectively. The curves are valid for Stockholm and windows facing east/west.

Table 4 shows possible energy savings with insulated window shutters. The values valid for east/west orientations can be considered averages for all compass points and can be used for approximate calculations. However, the distribution of window orientation should then be taken into account.

Table 4. Energy savings due to window shutters, comparison between
alt. 2 and alt. 4, kWh/m^2 year (Sept.-May). For the window, $k_{t,1}$ =
4.0 W/m^{2}K has been assumed. Percentage gain: E/W = (alt. 2 - alt. 4)
100/alt. 2.

Location	N	S	E/W	
Luleå	449	395	426	90%
Stockholm	333	280	311	115%
Malmö	292	248	273	124%

The values for energy savings listed in Table 4 are valid for $k_{t,1}$ = 4.0
W/m^{2}K for the window itself. For k = 3.0 (relatively new, well-weatherproofed
windows) the values in the table are all reduced by about 1/3 (to 66-68
percent of listed values).

5.   WINDOW SHUTTERS AS AN ENERGY FACTOR

5.1   The importance of windows for energy consumption

The energy consumption in buildings is determined by different construction
and operational factors, of which the windows are one of the most important.
However, the parameters which determine energy consumption show consider-
able variations, e.g. the quality of insulation and ventilation. To these
must be added large variation in the thermal performance of windows.

In view of this, it is difficult to define values for the importance of
windows as an energy factor. Based on calculations for actual structures
and with air leakage taken into account, one can estimate that windows
account for an average of 20 to 25 percent of applied energy (for heating
of rooms). The balance is distributed in about equal amounts between
other transmission (through walls, ceiling, etc.),air exchange and
hot water. This percentage for the window applies only to heat losses
(i.e. does not take into account incoming solar radiation). In a recent
research project, the share of windows in the yearly energy balance was
determined, for different types of apartments and different heating system
design. (Adamsson, 1974).

Table 5. The calculated share of windows (kWh) in the yearly heat
balance for two types of residences in Stockholm. Nominal* room tempera-
ture 21°C.

---

* Original uses the word "efterstravad", literal translation "strived for",
  indicating efforts to maintain the room temperature near 21°C.
  (Translator's note)

	Alt. A[a]			Alt. B[b]			Alt. C[c]		
	Removed	Added	Diff.	Remov.	Added	Diff.	Remov.	Added	Diff.
Small single home, 125*m²	6000	1000	-5000	6000	4000	-2000	4000	6000	+2000
Apartment 75*m²	2900	-	-2900	2900	1800	-1100	1900	1800	-100

[a]Moderate standard, no thermostat control, thus limited possibilities to utilize surplus heat, e.g. solar heat.

[b]Thermostats in each room make it possible to utilize surplus heat.

[c]3-pane windows, mainly facing south.

It is evident that, in Stockholm, 3-pane windows that mainly face south can give a heat surplus. Insulated shutters, alt. 4 in Table 2, give additional heat gain. In Stockholm, windows facing east/west will also give a net heat gain, as will windows facing southeast/southwest in Luleå.

Insulated shutters will thus give increased possibilities to obtain heat gains from solar radiation.

5.2 Energy savings through use of shutters

5.2.1 Statistical data base

There are no official statistics over window areas in existing buildings. The average values listed in Table 6 (m²/dwelling) is based on analysis of heat economy in buildings performed by the National Housing Board (Bostadsstyrelsen).

Table 6. Estimated specific** and total window area for heated buildings in the country (industrial buildings excluded)

Type of building	No. of dwellings[a]	Window area	
		m²/dwelling	m² total
Apartment houses	2.0×10^6	10	20.0×10^6
Single fam. homes	1.4×10^6	20	28.0×10^6
Other dwellings[b]	1.8×10^6		25×10^6
Vacation homes[c]	0.6×10^6		6.4×10^6
		Total	79.4×10^6

* Floor area.
* See translator's note on p. 35.

[a]According to EPU (DS I 1973:2)*

[b]Includes schools, offices, business establishments and similar dwellings.
Estimate is based on total building volume (DS I 1973:2, Table 8:3)*

[c]Constructed to permit year-round use.

If heated workshops and other industrial buildings are included, the
total window area may amount to at least 100×10^6 m^2, half of which is
in residential dwellings.

5.2.2 ⁻Energy savings per dwelling

Assume that the window area per dwelling is that listed in Table 6.
If the windows are uniformly distributed around the house one can
consider the values for E/W in Table 4 to be averages. For Stockholm's
latitude, the possible savings by using shutters in a small one family
house would then be

$\Delta E \approx 20 \times 310 \approx 6200$ kWh/year, house

This value applies to useful energy (net energy). Assuming e.g. an oil
furnace with 65 percent efficiency the corresponding supplied energy
would be $\Delta E \approx 62000/0.65 \approx 10,000$ kWh/year, house.

For apartment houses

$\Delta E \approx 10 \times 310 \approx 3100$ and 3100/0.80 $\approx$ 3900 kW/year, dwellings, respectively.**

Using EPU's values for average energy consumption (SOU 1974:64, page 141)***

Small one family homes 26,900 kWh/year (net) = about 40,000 kWh/year,
(gross).
Apartment houses 17,500 kWh/year (net) = about 20,000 kWh/year (gross).
One obtains the percentage of savings due to shutters, based on total
energy requirements, for:

Small one family houses $\Delta E \approx 10,000 \times 100/40,000 \approx 25$ percent

Apartment houses $\Delta E \approx 3,900 \times 100/20,000 \approx 20$ percent

The savings are higher if the windows face mainly northward and lower if
they face mainly towards the south. This is true for energy savings with
shutters (during the night). An increase in the relative window area

---

* EPU - Energiprognosutredningen = Energy Prognosis Study, published by
  Statens Industriverk, which in English is National Industry Board.

** An efficiency of 80 percent is evidently assumed for an apartment house.
   (Translator's note)

*** SOU = Statens Offentliga Utredningar = National Public Studies.

-40-

towards southern directions will on the other hand give increased heat
gain due to the incoming radiation during the day (Table 2). <u>Note</u>: For
dwelling having relatively new, well-weatherproofed windows ($k_t = 3.0$)
the values for energy savings given above should be reduced by about 1/3.

5.2.3   Total energy savings

For estimated total window area (5.2.1) and average savings due to
insulating shutters (Table 4) one obtains a total, theoretically possible,
energy savings $\Delta E_{tot} \approx 100 \times 10^6 \times 310 \approx 31 \times 10^9$ kWh/year.

For various reasons, all windows can naturally not be equipped with
insulating shutters. However, even if this is done to a limited extent
and over a time period, the resulting energy savings will be a significant
contribution towards improved conservation of energy.

Let us assume that one half of the window area in heated dwellings is
equipped with insulating shutters and that this is done at a rate of
10 percent per year. With a new construction rate of 80,000 dwellings
per year, half of which are equipped with shutters and assuming oil heat
with an average efficiency = 75 percent, the yearly savings in <u>supplied
energy</u> is

$$\Delta E_{tot} \approx 1.5/0.75 + 10^{-9} \ (20{,}000 \times 10{,}000 + 20{,}000 \times 3{,}900) \ \text{TWh/year}$$

$$\Delta E_{tot} \approx 2.3 \ \text{TWh/year}$$

To this value should be added the contribution from other kinds of heated
buildings produced, estimated at 0.2 TWh/year.

$$\Delta E_{tot} \approx \underline{2.5} \ \text{TWh/year}$$

As a comparison, the following values given by EPU should be mentioned.

Total energy consumption in residential dwellings (gross for 1972) 106.7 TWh/year

Total energy consumption in vacation homes (1972)   2.4 TWh/year

Savings if ½ of all small single family homes were equipped
with 3-pane windows   1.35 TWh/year

Savings if 9 cm thick mineral wool insulation were added in all
existing masonry walls having k-values = 0.75 to 0.90 W/m²K   2.6 TWh*

Let us note that for insulating window shutters, as in the case of added
insulation, the savings are expressed in <u>yearly increases</u>**. The energy
savings grow from year to year. In the case discussed here, for window
shutters it will be 12.5 TW h for the fifth year, if the assumptions are
realized.

---

* Should probably be 2.6 TWh/year. (Translator's note)
** The author assumes that a certain percentage of existing buildings are
   provided with shutters each year. (Translator's note)

5.2.4 Effects on design criteria

It should be of interest to establish how insulating window shutters would affect the <u>design criteria on power</u>, i.e. the power capacity for which heating systems for dwellings must be designed. However, this aspect has not been considered a part of the present study task. (The relations between energy consumption, energy savings and required power capability have not been made a specific topic for the research task at hand). An idea of the magnitude of the power savings that can be realized is provided by the following example. One can neglect incoming solar radiation and only consider the difference in k-values ($k_{t,1}$) for 2-pane windows with and without insulating shutters. For an ordinary small one family home having a window area of 20 m^2 and a design temperature* of $-18°C$ one obtains:

Power savings = 20 x 40 (4.0 - 0.7) = <u>2,640</u> W

If one half of all existing buildings were equipped with insulating window shutters, the total theoretically possible savings of power capacity would be $50 \times 10^6 \times 40 (4.0 - 0.7) \, 10^{-6}$ = <u>6,600</u> MW.

6. ECONOMICAL EVALUATION

6.1 Notations and definitions

K_e	energy cost	kr**/m^2
E_p	energy price	öre**/kWh
K_a	construction cost (investment), window shutters	kr/m^2
A	annuity factor	percent
n	amortizing time	years
N	usage time (life time)	years
p	capital interest (loan interest, internally required return on investment)	percent
R	return on construction cost	percent

---

* The outside temperature for which the heating system is designed to provide a reasonable indoor climate. (Translator's note)

** Swedish crowns, (kronor), approximately $0.23, 100 öre = 1 krona. (Translator's note)

The following relation applies

$$A = \Delta K_e \quad 100/K_a = \Delta E \; E_p \; 0.01 \quad 100/K_a = \Delta E \; E_p/K_a \text{ percent}$$

Values for ΔE = energy savings with shutters are obtained from Table 4.

6.2 Technical considerations

With the present state of technical development one is faced with certain problems when it comes to evaluating the cost effectiveness of insulating shutters. The market price is naturally dependent on demand. Since no series production is currently under way, cost for manufacture and installation must be estimated. In this process the following cases should be considered separately.

Shutters for existing buildings

One must consider the existing conditions, i.e. window size, location and design, as well as wall and facade* material. A preliminary study reveals that diverse window dimensions will not prevent manufacture of large series of the same dimension. A few window dimensions appear to be clearly dominating.

Application of shutters to existing buildings is not only a technical question but is also a matter of appearance. On the other hand, insulating shutters should, in many cases, with suitable design and color selection, be a stimulating addition to the street scenery.

Integrated window shutter production
will primarily be possible for new construction, but also when replacing windows in existing buildings. Integrated production offers good opportunities for matching the shutters - technically and aesthetically - to windows and walls as well as to the facade. Integrated production should also offer distinctive cost advantages.

Planning for shutters

When insulating shutters are to be used, it is desirable that these are designed in already during the planning stage, among other things, due to the space required for the shutters.

6.3 Energy cost

The cost of energy has a dominant effect on shutter economy. In principle, one should consider expected cost developments, since the economical judgement should be based on the average cost of energy during the lifetime of the shutters. Except for the actual cost of production,

---

* The word "fasad" in the original refers to the outer layers of the wall structure, i.e. the "siding". (Translator's note)

-43-

energy costs are affected by a number of other factors, ranging from general price developments (inflation) to ecological considerations and limitations of resources.

6.4   Power savings

The effect of shutters on the required power capacity (differential cost) should be considered for new construction, as well as when the heating system is replaced or converted in existing buildings. Reductions in power requirement and construction cost obtained by use of shutters should in principle be distributed per m^2 window area (A_f) and the construction cost (K_a) is hereby reduced. However, in line with the discussion in 5.2.4, this effect will here be neglected. In case of widespread use of insulating shutters, as for added insulation in general, one will on the other hand probably obtain power gains which should be considered in connection with energy requirement forecasts and planning.

6.5   Beneficial aspects in addition to energy savings

In addition to energy and power savings, other beneficial effects are obtained with insulating window shutters. For example, the primary objective may in many cases be improved sound insulation, a requirement that has recently been raised, e.g. by a report from the traffic noise study (SOU: 60,1974)*. Commonly used shutters normally have a decorative function only, which should be possible to obtain also with insulating shutters. In this context one should also mention noise reduction in the street, black-out and sun shading. Desirable side effects like these should, if possible, be considered in the cost evaluation.

Thus, in cases where insulating shutters are primarily justified by requirements for noise reduction, cost comparisons between different solutions (which meet the noise requirements) should take into account also energy savings, as well as other functions that are relevant from a cost point of view. In other cases, energy savings may be the primary objective, while the shutters also meet requirements on better sound protection.

To the extent that shutters replace other required equipment, e.g. venetian blinds or black-out curtains, the construction cost for the shutters should be reduced by the corresponding amount. The same applies to any power gains that may be realized. Effects such as improved sound insulation, increased protection against break-ins and fire should, if a value can be assessed, in principle be included in the yearly savings of energy. Analysis of the importance of these side effects has not been considered a part of this study task. Cases described in the following are thus based exclusively at the energy gains shown by computed cases (Table 4).

---

* SOU = Statens Offentliga Utredningar = National Public Studies.

6.6 Energy gains and economy - computed examples

The economy of the window itself has been studied, e.g. by comparing 2- and 3-pane windows (B. Adamsson and I. Höglund, 1957, and other). In the present study, comparison is made between 2-pane windows with and without insulating shutters, i.e. alt. 2,3 and 4 according to computer calculations (4.3.2). Yearly energy savings with shutters are obtained from Table 4. For the window we thus assume $k_{t,1}$ = 4.0 W/m²K. A free horizon (no shadowing) is assumed.

Figure 14 shows the economy of shutters when optimally utilized (comparison of alt. 4 and 2. The annuity factor (A) is obtained as function of the energy price. The R-scale gives (to A) the interest corresponding to the invested capital (K_a) for an assumed usage time of 30 years; the n-scale shows the time required for amortizing invested capital with an interest rate of 5 percent.

Note: Beginning in 1975, the annuity for rental and condominium houses is 4 percent (1st year),according to the residential financing law. It is assumed that the annuity increases slowly with inflation. If fuel costs follow the general price development (the inflation), this means that the economical result remains approximately constant. If energy costs increase faster, which seems probably, the economical result is improved correspondingly.

The curves pertain to windows facing E/W for Luleå, Stockholm and Malmö. Solid lines are valid for K_a = 500 kr/m². This cost refers to shutters installed in existing apartment houses in Stockholm, according to an estimate by Stockholmshem AB* (Dec. 74). This estimate was primarily made for a limited number of windows for which the sound insulation will be improved.

Continuous series production and installation of shutters in large volume should result in a lower price, possibly 400 kr/m², which corresponds to the broken curves in Figure 14. As an example, K_a = 400 and E_p = 10 results in A = 7.8 percent, R = about 6.5 percent, n = about 21 years, for Stockholm and windows facing E/W.

Figure 15 illustrates the importance of window orientation for Stockholm. Solid curves pertain to N, S, E/W and optimum use of the shutters (alt. t). Broken curves relate to N and S according to alt. 3, i.e. with somewhat shorter closing time for the shutters than in alt. 4. For all cases, K_a = 400 kr/m² applies.

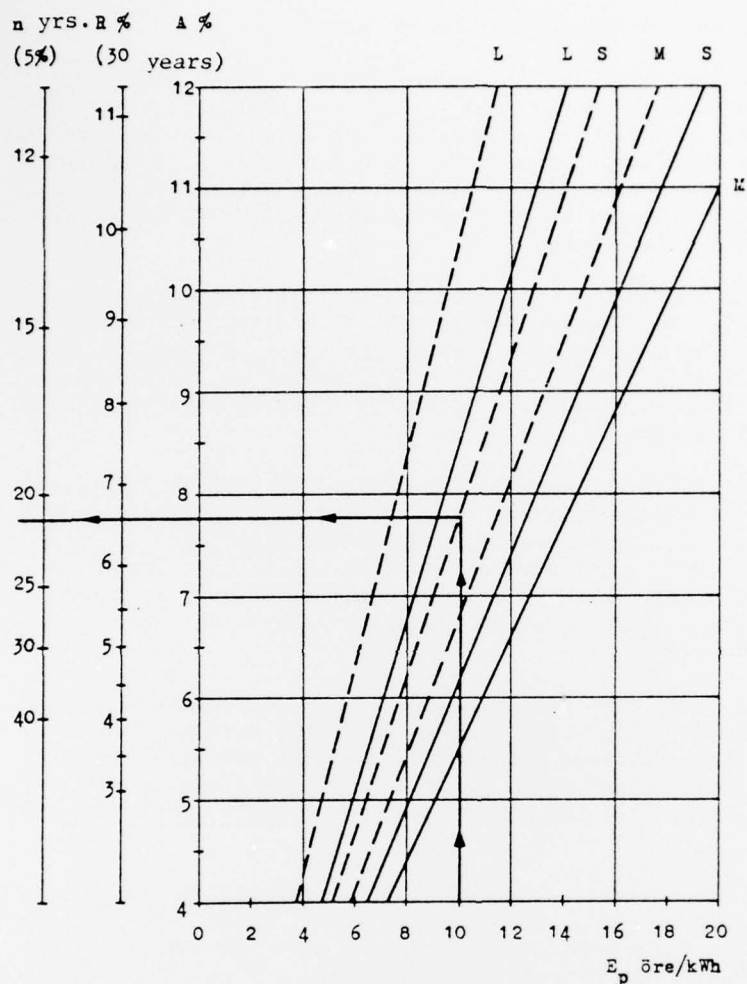* Real Estate development or consulting firm. (Translator's note)

-45-

Figure 14. Window shutter economy with respect to energy savings as a function of energy cost (E_p). Comparison between alt. 2 and 4 according to computer calculations. The curves pertain to installation in <u>existing</u> houses in Luleå (L), Stockholm (S) and Malmö (M). Compass point E (W). <u>Solid</u> curves K_a = 500 kr/m^2. <u>Broken</u> curves K_a = 400 kr/m^2.
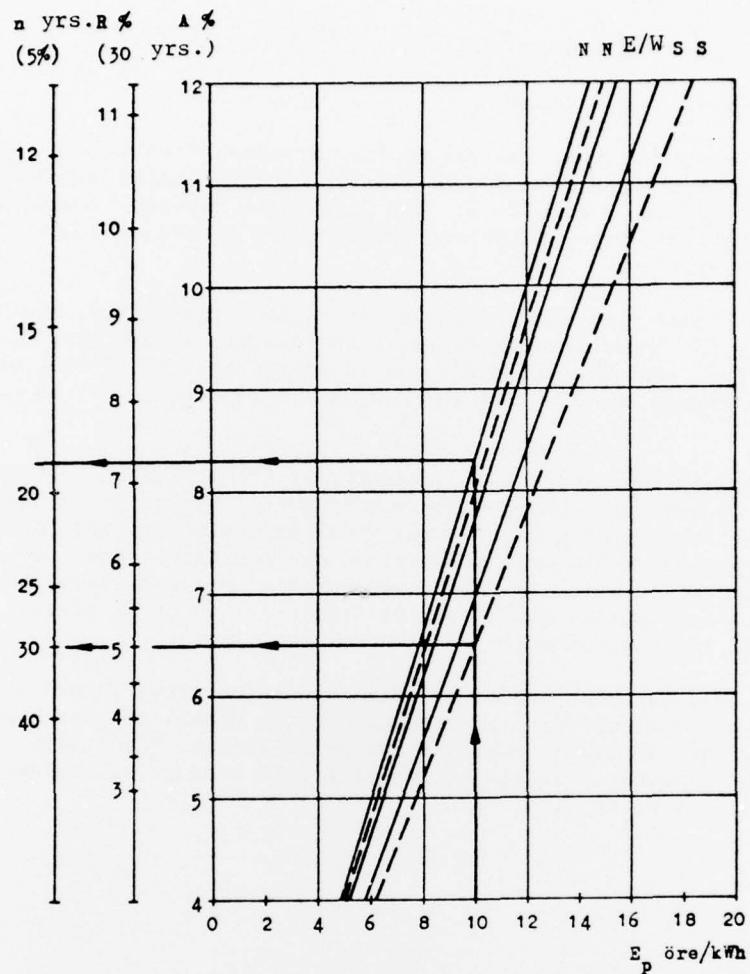
-46-

Figure 15. Window shutter economy with respect to energy savings as a function of energy cost (E_p). <u>Solid</u> curves = alt. 4, compass points N, E (W), S, shows effect of window orientation. <u>Broken</u> curves = alt. 3. The curves pertain to Stockholm and K_a = 400 kr/m^2.

For example, Figure 15 shows that for E_p = 10 one obtains, for windows facing:

South   A = 7.0   R = about 5.7   n = about 26

North   A = 8.3   R = about 7.3   n = about 18

Furthermore, one finds that the value of A increases from 6.5 to 7.0 for windows facing south and from 8.0 to 8.3 for windows facing north, when one changes from alt. 3 to alt. 4. The difference between these alternatives in the time during which the shutters are closed has thus a minor effect on the economy.

Integrated production of windows and shutters in large series, and some consideration for lower investment required (6.2.3), should give K_a = about 300 kr/m^2. For Stockholm E/W and an energy cost of 10 öre, one obtains from Figure 16 A = 10.4 percent, R = 9.7 percent, n = 13 to 14 years.

In the previously mentioned study conducted by Stockholmshem, the main purpose was to meet requirements for better sound insulation. A calculation of the economical return of the simultaneously obtained improvement in heat insulation should then be based on the additional cost for thermally insulating material, which in this case probably does not exceed 50 kr/m^2. With the same assumptions as before, we obtain A = about 62 percent (for added thermal insulation) which gives n = 1 to 2 years.

Comparative cost calculations of the kind presented above should be verified by post calculations in connection with practical tests of insulating window shutters. Comparative calculations of economic return should to the greatest possible extent take into account all relevant costs and aspects on utility.
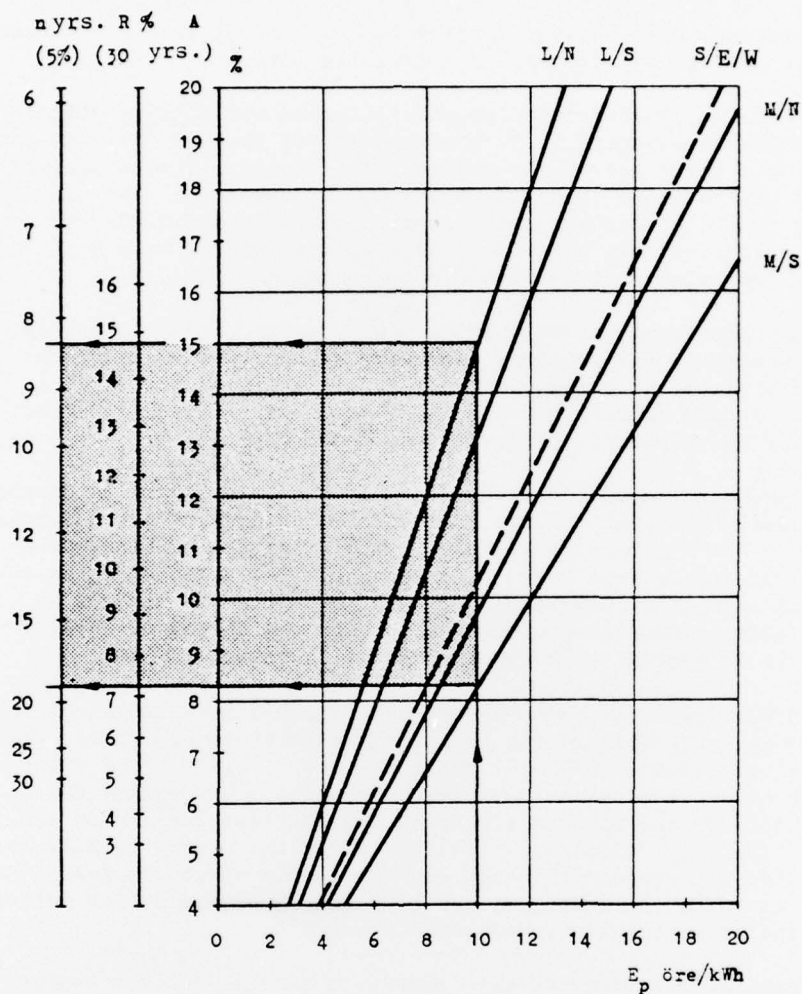
Figure 16. Window shutter economy with respect to energy savings as a function of energy cost (E_p). Comparison between alt. 2 and 4 according to computer calculations. Integrated production of windows and shutters assumed, K_a = 300 kr/m². <u>Solid</u> curves Luleå and Malmö, respectively. <u>Broken</u> curve Stockholm. Compass point E(W).

7.   DISCUSSION AND SUMMARY

The report initially analyzes the <u>thermal performance</u> of windows and window shutters. It is found that this performance depends on a number of incompletely known variables: window design, quality, orientation, type of ventilation, surrounding buildings and terrain (which can affect incoming solar radiation), geographical location, etc.

The main body of the report clarifies and discusses the <u>thermal effects</u> of insulating window shutters, i.e. how they affect the heat balance for windows, indoor climate and energy consumption. Results from computer evaluation of energy flows (heat losses, incoming radiation) for different points of the compass, months and geographical locations (Luleå, Stockholm, Malmö)*. Calculations were made for 2-pane windows alone, wall structures (k = 0.7), and two alternatives with window shutters.

It is concluded that comparatively large energy gains should be possible with suitably designed and properly used window shutters. Comparisons are made with other means for saving energy. In addition, beneficial effects on the indoor climate are obtained, which can indirectly affect energy consumption by permitting lower room temperature.

Finally, the <u>economy</u> (return on investment) of window shutters is discussed. Based on available research results, these calculations are made assuming a k-value = 4.0 W/m^2K for 2-pane windows, with transmission (including edge losses) and air leakage taken into account. The selected value should be regarded as a practical average which can be applied to windows in existing buildings. Another decisive factor for the choice of k-value was an analysis of thermal performance for the shutters.

For new, well-weatherproofed windows one can assume a lower k-value, say 3.0 W/m^2K. The energy gain during the time the shutters are closed will then decrease correspondingly, i.e. to (3.0 - 0.7) 100/4.0 - 0.7 = about 70 percent of calculated values. However, the choice of k-value for windows also affects the time during which the shutters are closed and thus also the incoming radiation as well as the total energy balance for the window. The difference in energy savings due to shutters, for different k-values for the windows, can thus not be obtained with better accuracy by the proportioning method used above.

Additional computer calculations were therefore carried out for 2-pane windows having a k-value = 3.0 W/m^2K (Table 3). These calculations show that the heat gain due to shutters (alt. 4/alt. 2) is reduced by about 1/3, compared to the values that are obtained for k = 4.0 (Table 4).

_____

* Approximative latitudes (North): Lulea 65.6°, Stockholm 59.0°, Malmö 55.5°. Examples of towns in Alaska on about these latitudes are: Fairbanks, Skagway and Ketchikan, respectively. (Translator's note).
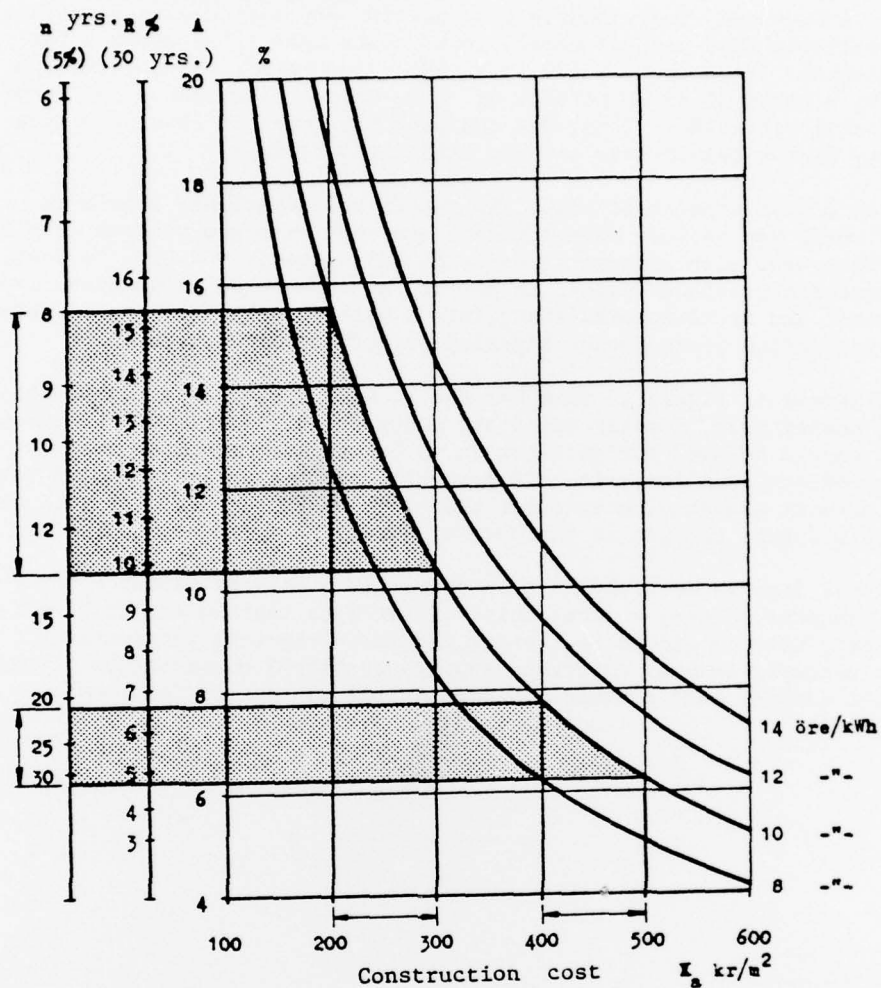
Figure 17. Window shutter economy with respect to energy savings as a
function of construction cost (K_a) for different energy costs (E_p).
Comparison between alt. 2 and 4 according to computer calculations.
The curves pertain to Stockholm E(W) (= approximate mean for the country).

-51-

The expression determining economy* is the ratio between calculated savings and construction cost (6.1). For integrated production of (new) windows and window shutters, a preliminary cost evaluation (Jan. 75) indicates that one can expect lower costs than those assumed for the diagrams (Figures 14 - 17), i.e. 300 - 500 kr/m^2. A construction cost K_a = about 65 to 70 percent of these values, i.e. 200 - 350 kr/m^2, would seem realistic. Thus, one can probably count on about the same annuity factor (A) in both new and existing buildings.
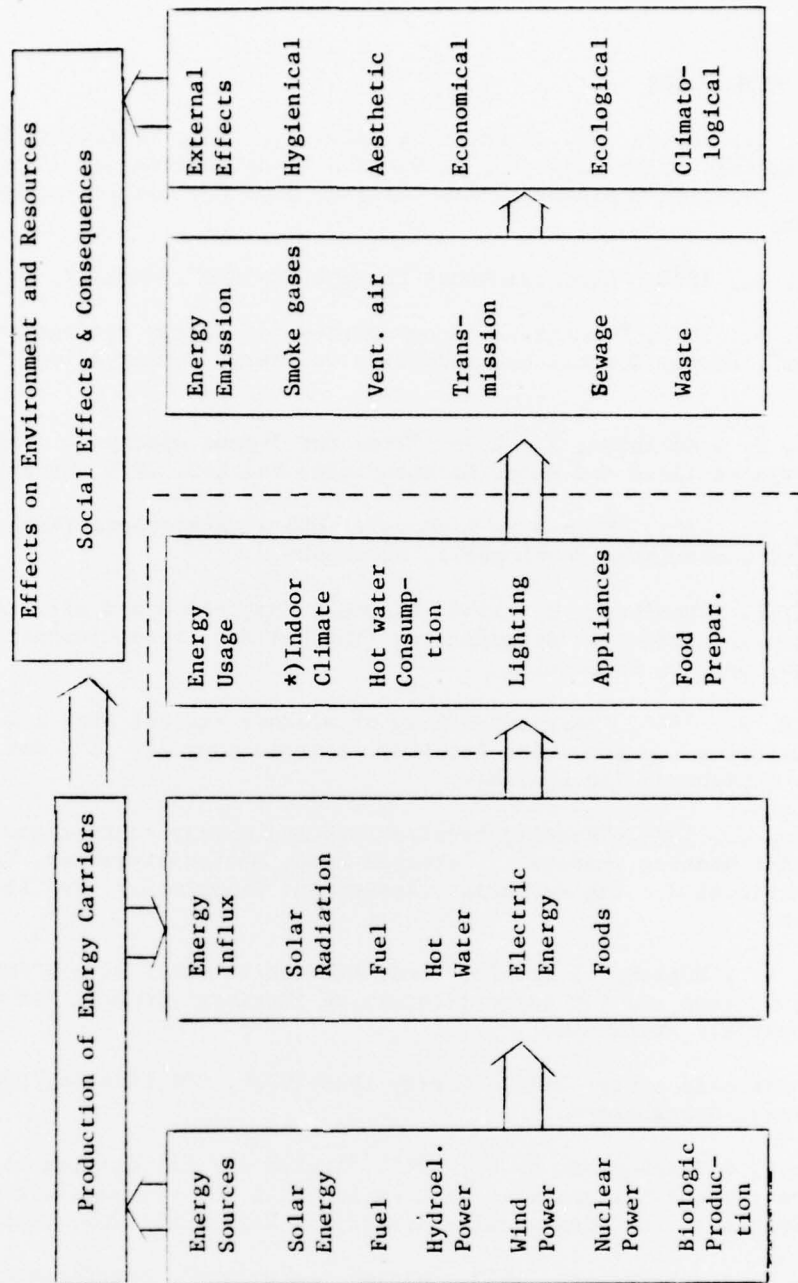
From an economic point of view, the return on investment* should in other words not be less when shutters are used with new windows (k = 3.0) than when used with windows in existing buildings (k = 4.0). In fact, the economic prospects should be better for integrated production (from technical and architectural viewpoints), with possible savings in terms of construction costs (power capacity, venetian blinds, etc.)

The diagrams in Figure 17 show how the economy varies with construction cost, energy cost, compass point and geographical location. The calculated cases should be used for guidance only, but could serve as a base for a more complete cost analysis. If possible, such an analysis should take into account useful effects other than mere energy savings, as well as probable future changes in the cost of energy.

Energy savings is not only or even primarily a private matter - nor one that concerns housing economy only. Efforts to improve the utilization of energy must be judged in a wider and more long-term perspective, where concepts such as emergency supply capacity** conservation of resources and ecology lend a broader aspect on the concept of "economy". (Figure 18)

---

* The word "lönsamhet" used here and in many other places has no direct English equivalent. Depending on the context, the best translation could be: economy, return on investment, profitability or financial gain. (Translator's note)

** The word "försörjningsberedskap" used in the original alludes to the fact that Sweden imports most of its energy (oil, coal, etc.) and faces possible cut-off of these supplies in case of war or similar situations. The capacity for storage of oil and coal is thus a major consideration for the ability to weather such an emergency. Reduction of the overall energy/consumption will reduce the required capacity for emergency storage, or make stored resources last longer if the shut-off comes.

Effects on Environment and Resources

Social Effects & Consequences

Production of Energy Carriers

External Effects

Hygienical

Aesthetic

Economical

Ecological

Climato-logical

Energy Emission

Smoke gases

Vent. air

Trans-mission

Sewage

Waste

Energy Usage

*)Indoor Climate

Hot water Consump-tion

Lighting

Appliances

Food Prepar.

Energy Influx

Solar Radiation

Fuel

Hot Water

Electric Energy

Foods

Energy Sources

Solar Energy

Fuel

Hydroel. Power

Wind Power

Nuclear Power

Biologic Produc-tion

*) Indoor Climate (Heating, Air conditioning, Humidif., etc.)

Figure 18. This flow diagram describes a building in the form of an "energy system" and its interfaces with the surrounding world through, in general, irreversible effects on the <u>environment</u> and <u>consumption of resources</u>.

-53-

8 REFERENCES

Adamsson, B., Boysen, A., Brown, G. & Holm, L., 1965, "Building design for and against solar radiation". Svenska Teknologföreningen, Kursverksamheten, (Swedish Engineering Association, Div. for Continuing Education) Stockholm.

Adamsson, B., 1972, "Heat transport through windows", Summary.

Adamsson, B., 1974, "Technical opportunities for energy savings in buildings", Energy Council questionnaire on energy conservation, Dec. 18, 1974.

Adamsson, B. & Källblad, K., 1975, "Time for 3-pane windows". Väg och vattenbyggaren (Road and Water Construction) Vol 1-2, 1975, Stockholm.

Backmark, L., 1966, "Side-hung windows". HSB:s riksforbund (Real Estate and condominium developers), Stockholm.

Bergvall, L. & Dahlberg, E., 1944, "Thermal insulation and air leakage prevention in windows". Byggmästaren (The Builder, trade journal) No. 15, Vol. 1944, pp 1-9, Stockholm.

Byberg, M. R., 1970, "Weatherproofing of windows against wind and rain", Byggeindustrien (Construction Industry, a trade journal) 19, Oct., vol. 21, Copenhagen (in Danish).

Cederholm, J., 1974, "Heating requirements and energy consumption for residential heating systems". Internal Memo, Bostadsstyrelsen, Värderingsbyrån (National Housing Authority, Assessment Department), May 15, 1974, Stockholm.

Elmroth, A. & Höglund, I., 1973, "Heat balance in small single family houses", Statens råd for byggnadsforskning (National Council for Construction research), Stockholm.

Energy prognosis study, 1974, "Energy 1985-2000", SOU 1974:64, Department of Industry, Stockholm**.

Höglund, I. & Stephensen, D. G., 1968, "Tables for calculating solar radiation towards buildings". Statens institut för byggnadsforskning (State Institute for Construction Research), Report 49:1968, Stockholm.

Höglund, I. & Ahlgren, B., 1973, "Window Technology", Byggförlaget (Publishing company), Stockholm.

Höglund, I., 1974, "Solar energy for buildings", VVS (trade journal), vol. 9, Stockholm.

---

* In Swedish, unless otherwise noted. (Translator's note)
** SOU = Statens Offentliga Utredningar = National Public Studies

Isfält, E., 1974, "Optical and thermal properties of windows and sunshades", Stockholm.

Lyng, O., 1965, "Heat transport through windows", Statens råd för byggnadsforskning (State Council for Construction Research) Report 15/65, Stockholm.

Munther,K. E., 1974, "Energy consumption in small single family homes", Statens råd för byggnadsforskning (State Council for Construction Research), Report 58:1974, Stockholm.

Petersen, E., 1966, "Solar radiation through windows", Danmarks tekniske højskole, Laboratoriet for varmeisolering (Technical University of Denmark, Laboratory for Thermal Insulation), Bulletin No. 13, Copenhagen (in Danish).

Pleijel, G., 1954, "The computation of natural radiation in architecture and town planning", Statens nämnd* för byggnadsforskning (State Council for Construction Research), Bulletin No. 25, Stockholm.

Pleijel, G., 1959, "Thermal balance in windows", Byggmästaren (trade journal) No. 1, 1959, Stockholm.

Schüle, S., 1962, "Investigation of air and heat conduction through windows", Gesundheits - ingenieur, (The health engineer, German trade journal), No. 6, pp. 153-184 (in German).

Seifert, E. & Froelich, H 1974, "Measurements of air leakage in windows of various designs in residential dwellings". Österreichishes Institut für Bauforschung (Austrian Institute for Construction Research), Research report 117/2, Vienna.

Wigen, R., 1963, "Windows, technical and economical aspects", Norges byggforskningsinstitutt (Norwegian Institute of Construction Research), Handbook 15, Oslo.

---

* Same agency as "Statens råd"...; the name was changed after 1954. (Translator's note).

Windows as an energy factor   Folke Hagman